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FIRE SAFETY ANALYSIS OF THE USCGC DEPENDABLE

FINAL REPORT
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N O T I C E

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16. Abstract (MAXIMUM 200 WORDS)

This report documents the results of a fire safety analysis of the USCGC DEPENDABLE prior to and after implementing changes associated with the Paragon project. The Paragon project reduces the normal crew by approximately 20% and implements a number of changes to supplant the loss of manual firefighting effectiveness. These changes include a new fire detection and monitoring system, installation of fixed surveillance cameras, and utilization of a rapid response team concept.

The Ship Fire Safety Engineering Methodology (SFSEM) and associated computer program, SAFE version 2.2, were utilized as an analytical tool to perform the analysis. The SFSEM is a probabilistic based fire risk analysis methodology. It is useful to conduct a structured and comprehensive analysis of the performance of all types of surface ships as a fire safety system. The SFSEM provides an integrated framework for analyzing fires on ships in comparison to established fire safety objectives. It accounts for all relevant aspects of fire safety including the growth and spread of fire, the effectiveness of passive design features such as barriers, and active fire protection features such as fixed and portable fire extinguishing systems, as well as manual fire suppression.

SAFE implements the SFSEM and evaluates the probability of spaces and barriers limiting a fire. The evaluation is conducted on a compartment-by-compartment basis. SAFE calculates the probable paths of fire spread for user-specified time duration. SFSEM/SAFE has been successfully used to analyze the fire safety design of existing as well as proposed ships.

SAFE input data included information collected during a ship visit to the CGC DEPENDABLE during the period 30 September – 3 October 1997. Baseline fire safety analysis results show that with just passive fire protection in effect (without considering automated or manual fire protection), all compartments in the DEPENDABLE exceed fire safety objectives, both in port and at sea. Automated and manual firefighting attributes increase the margin of safety provided by passive protection. The post Paragon fire safety analysis shows improvement in fire safety in all scenarios. Recommendations are provided to implement the rapid response team concept on all other cutters in the Coast Guard and modification of fire detection systems on other cutters.

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EXECUTIVE SUMMARY

The Coast Guard commenced the Paragon Project to more effectively and efficiently operate a 210' WMEC in all mission areas, with an eye cast toward opportunities for crew-size reduction. The USCGC DEPENDABLE (and crew) was selected as the test vessel to evaluate this new operational philosophy. The Coast Guard is evaluating all aspects of operating DEPENDABLE with a reduced crew, including effects on fire safety, watchstanding, maintenance, and mission performance. The objectives of this study are to perform fire safety analyses of fire protection levels of pre-Paragon and post-Paragon conditions on board DEPENDABLE to ensure that an acceptable level of fire safety is achieved in both configurations. The scope of this project includes a comparison of results of these analyses.

The Ship Fire Safety Engineering Methodology (SFSEM) and associated computer program, SAFE version 2.2, were utilized as an analytical tool to perform the analyses. The SFSEM is a probabilistic-based fire risk analysis methodology. It is useful to conduct a structured and comprehensive analysis of the performance of all types of surface ships as a fire safety system. The SFSEM provides an integrated framework for analyzing fires on ships in comparison to established Fire Safety Objectives (FSO). It accounts for all relevant aspects of fire safety, including the growth and spread of fire, the effectiveness of passive design features such as barriers, and active fire protection features such as fixed and portable fire extinguishing systems as well as manual fire suppression.

SAFE implements the SFSEM and evaluates the probability of spaces and barriers limiting a fire. The evaluation is conducted on a compartment-by-compartment basis. SAFE calculates the probable paths of fire spread for a user-specified time duration. SFSEM/SAFE has been successfully used in the past to analyze the fire safety design of existing as well as proposed ships.

SAFE input data for the pre-Paragon analysis included information collected during a ship visit to the DEPENDABLE during the period 30 September to 3 October 1997. The baseline (pre-Paragon) fire safety analysis results show that all compartments in the pre-Paragon DEPENDABLE exceed FSOs, in port and at sea. Moreover, all compartments exceed FSOs with just passive fire protection in effect. Automated fire protection systems and manual firefighting efforts serve to increase the margin of safety provided by passive fire protection. This means that no improvements are necessarily required to bring the pre-Paragon DEPENDABLE up to minimally acceptable fire safety levels.

The following changes associated with the Paragon project were implemented on DEPENDABLE:

- The original zoned fire detection system was changed to a fully addressable system.
- Sixteen fixed surveillance cameras were installed in strategic locations throughout the vessel. TV monitors located throughout the ship constantly display the view from one of the cameras.
- The fire detection and monitoring system is integrated with other alarms, including bilge high water level and magazine high temperature. The system is also integrated with the surveillance cameras, TV monitors mounted in strategic locations, and the general

announcing system. The system is designed to automatically make an announcement of the precise location of a fire as soon as it is detected. In addition, the nearest surveillance camera automatically locks in so that all TV monitors provide a continuous view of the scene near the fire.

- A four- to five-person Rapid Response Team (RRT), modeled after a concept developed by the Navy, is used to immediately respond to all fires in port and at sea.
- At sea and in port, away from homeport, one repair party is billeted to be manned (as compared with two repair parties in other 210' WMEC cutters).
- In homeport, the normal duty section is reduced to five persons. Reliance is placed on the assistance available from the city fire department as well as from other cutters that may be in port at the time.
- Most crew members have been issued personal portable wireless communication devices.

Some of the changes implemented on DEPENDABLE as a result of the Paragon Project increase the fire safety of the cutter, while other changes have an adverse effect on fire safety. The net effect on the fire safety of the DEPENDABLE as a result of the Paragon changes is significantly positive or beneficial for all scenarios. The average increase in fire safety of the post-Paragon cutter compared to the pre-Paragon cutter varies from 15.3% for the in homeport, XRAY, scenario to 30.5% for the at sea scenario. The post-Paragon fire safety analysis results show that all compartments exceed FSOs, in port and at sea. Furthermore, all compartments exceed FSOs with just passive fire protection in effect. Automated fire protection systems and manual firefighting efforts serve to increase the margin of safety provided by passive fire protection. This means that no improvements are necessarily required to bring the post-Paragon DEPENDABLE up to minimally acceptable fire safety levels.

As a result of performing the fire safety analysis of the post-Paragon DEPENDABLE, the following recommendations are offered for consideration by the Coast Guard:

- Besides the obvious benefits in damage control and firefighting, the personal communication devices issued to virtually all crew members has benefits in many other aspects of operating the cutter. All Coast Guard cutters could benefit from issuing these devices to their crew members.
- The Coast Guard should consider revising the firefighting procedures in all cutters to incorporate a rapid response team concept.
- All cutters with a fire detection system that can be similarly modified as on DEPENDABLE should be changed to a fully addressable system.
- The new fire detection and monitoring system has not been fully implemented in DEPENDABLE due to technical difficulties encountered during installation. It is recommended that this system be fully implemented to take full advantage of the increase in fire safety offered by the new system.

The appendices in this report include the AutoCAD drawings and comprehensive tables of input data used to populate the baseline data set in SAFE. The detailed spreadsheets for calculating the probabilities of flame termination are included as supporting data. The input and output data from the analysis of the post-Paragon DEPENDABLE are also included.

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LIST OF ABBREVIATIONS AND TERMS

A Curve - The resulting curve when A values for increasing areas of a compartment are plotted on a graph with probability of flame limitation on the ordinate axis (logarithmic scale) with the origin at the top left and the deck area of the compartment on the abscissa axis (linear scale). See "A Value."

A Value (%) - The probability that an automated fixed fire protection system installed in a compartment will successfully extinguish the fire before FRI occurs given that the fire did not self-terminate and was not extinguished by manual firefighting efforts. Each compartment is assigned three A-values: the probability of flame limitation given EB in the room of origin, the probability of flame limitation given EB has occurred in the room as a result of a thermal (T-bar) failure of a barrier, and the probability of flame limitation given EB has occurred in the room as a result of a durability (D-bar) failure of a barrier. In SAFE, these values are abbreviated OA, TA, and DA, respectively

Active Fire Protection - Fire protection features designed to limit flame movement by automatic detection, automatic/automated fire extinguishing systems, and manual suppression systems or equipment. Examples of active fire protection features are automatic sprinkler systems, fire extinguishers, and trained firefighting teams. See "Passive Fire Protection."

AFFF - Aqueous Film Forming Foam. A firefighting agent particularly effective against class B fires.

Alpha (kilowatts per second squared) - The fire growth coefficient in the pre-FRI heat release rate algorithm. Values for alpha are established for each fire growth model as documented in the SAFE User Manual, Version 2.2. See "Fire Growth Model" and "Pre-FRI Heat Release Rate."

Alternative Data Set - Data sets identified as "Alternative" have had the SAFE baseline input values adjusted, as necessary, to reflect the impact of the proposed alterations or modifications that affect the ship's fire-safety system. See "Baseline Data Set."

ASTM E119 Test Rating (hours and minutes) - A rating in hours and minutes specifying time to failure of a material or assembly in the standard fire test that is conducted in accordance with the requirements of ASTM E-119 standardized test methodology.

AutoCAD - Commercially available Computer Aided Design (CAD) software used to display the plan views of a ship's compartmentation on each deck level.

Barrier - Any vertical or horizontal surface that tends to impede, slow, or stop the spread of heat, flames, and combustion products from one space to another. In a ship, barriers may be bulkheads (joiner, watertight, or structural), decks, or overheads. See "Zero-Strength Barrier."

Baseline Data Set - Data sets identified as "Baseline" utilize input values to the SAFE program based on the physical condition of the ship found during the ship visit and are not influenced by any modifications or alterations that may be proposed as a result of an analysis. See "Alternative Data Set."

Blackout - The cessation of visible flaming (not to be mistaken for extinguishment, which is the cessation of combustion).

Bulkhead - The equivalent in a ship to a wall in a building. Bulkheads can be structural or joiner (nonstructural), insulated or bare. They may be constructed of aluminum, steel, or a composite such as Marinite or Nomex. Together with overheads, they serve to segment the ship into various compartments.

CBO (minutes) - Compartment Burnout - The point in the fire growth curve where complete consumption of all fuel due to pyrolysis occurs.

Ceiling Point - The point in growth of a compartment fire when the flames first touch or involve the ceiling.

Cellulosics - One of two classifications of fuel on board ship. Cellulosics are characterized as ash producing; examples are wood, paper, and textile products. See “Fuel Load” and “Petrochemicals.”

Class A Fire - A fire involving cellulosic-type products (wood, cotton, paper, etc.) that produce ash as a combustion product. Water is the primary firefighting agent and extinguishes the fire by cooling the fuel below the ignition point. See “Class B Fire” and “Class C Fire.”

Class B Fire - A fire involving flammable liquids (fuel oil, lube oil, gasoline, etc.) that burn vigorously without producing ash. AFFF is the primary firefighting agent and extinguishes the fire by smothering (local oxygen depravation) the fire with a thick layer of foam that floats on the surface of the fuel. See “Class A Fire” and “Class C Fire.”

Class C Fire - A fire involving energized electrical equipment. Class C fires frequently involve class A or B fires as well. Electrical fires are usually extinguished when the electrical power to the affected equipment is secured, however the associated class A or class B fire may continue to burn. CO_2 is the primary firefighting agent and extinguishes the fire by smothering (local oxygen depravation) the fire without damaging electrical or electronic components. See “Class A Fire” and “Class B Fire.”

CO_2 - Carbon Dioxide. A firefighting agent particularly effective against class C fires.

Combustion - Rapid oxidation in which a fuel pyrolizes or turns into a vapor and mixes with oxygen at an extremely rapid rate accompanied by the release of intense heat and light, visible as flames. See “Fire” and “Pyrolysis.”

Compartment - An enclosed space in a ship usually identified with a unique identifying number consisting of deck, forward frame, relation to centerline, and a letter designating the function or type of compartment. See “Plan ID.”

Condition of Readiness - One of three material conditions of readiness set by the Commanding Officer of a military ship. All accesses such as doors, hatches and scuttles, and other fittings having damage control value are labeled X, Y, or Z. In condition “XRAY,” all YOKE and ZEBRA accesses and fittings are open and those labeled XRAY are closed; in condition “YOKE,” all ZEBRA accesses and fittings are open while those labeled XRAY and YOKE are closed; in condition “ZEBRA,” all accesses and fittings are closed.

Configuration - The type of fire protection under consideration in a given fire scenario for a SAFE computer model run. Options include Passive only (I), Passive and Automatic

Detection/Fixed Fire extinguishing (I and A), Passive and Manual suppression (I and M), or all three (I, A, and M).

CUI - Compartment Use Indicator - An abbreviated designation for a compartment selected from a list provided in SAFE, which is used to define the type or function of the compartment and establish default values for various fire parameters.

Cum-L (%) - The accumulated probability that a fire will be limited (thus points on an "L-curve") in this or some previous compartment in a particular fire path. "1 - Cum L," therefore, is the probability that the fire will spread.

D-Adjust (%) - A user-specified parameter that can range from 0% to -99% to modify the D-bar values for a barrier. Usually used to account for deterioration of the barrier. An open door is not considered a derating of the barrier. See "D-bar."

Data Set - A data set describes those characteristics of a ship which affect its performance as a firesafety system. It includes information describing particular aspects of a compartment such as geometry, construction, fuel type and load, automatic detection and monitoring systems, ventilation, and fire protection systems. See "Alternative Data Set" and "Baseline Data Set."

D-bar (%) - The probability of a durability failure of a barrier, which would permit significant transfer of heat into the adjacent compartment.

Deck - The equivalent in a ship to a floor in a building. Decks can be continuous or stepped, insulated or bare. They can be constructed of aluminum, steel, or a composite such as Nomex. They can be covered with tile, carpet, or a poured floor covering such as terrazzo on one side and sheathing, insulation, or both on the other. Together with overheads and bulkheads they serve to segment the ship into various compartments.

Destroyed Barrier - When a barrier is "destroyed" in a model run, heat from the burning compartment is transferred to the adjacent compartment if that room is not at full room involvement. The amount of heat transferred is a function of the barrier material and is referred to as residual heat transfer. See "Residual Heat Transfer."

Door - An opening through a bulkhead providing access to a compartment. If a door is open it is equivalent to a durability failure of the associated bulkhead.

Dur IAM (%) - The probability of terminating a fire originating in a compartment due to a durability barrier failure. The probability is calculated from a combination of the I, A, and M curves for that room. If the room is a room of origin, Dur IAM is not applicable.

EB - Established Burning - The point in the fire growth curve between ignition and FRI when the fire starts to grow exponentially with respect to time. In SAFE, it is assumed that this exponential growth varies with the 2nd power of time. EB is usually considered equivalent to a flame 10 inches high. EB also signifies the demarcation between fire prevention and the beginning of the ship's response to the fire.

EEBD - Emergency Escape Breathing Device. This self-contained device provides 15 minutes of oxygen to an individual for the purpose of escaping from a fire.

Enclosure Point - The point in the fire growth curve where the fire starts to become influenced by a barrier.

Engineering Judgment - The assessment of risk in a probabilistic model utilizing subjective probabilities. In the SFSEM, engineering judgment is synonymous with an analyst's degree of belief. In this context an analyst is a domain knowledgeable individual whose judgment is augmented by all available data including results of deterministic computer models.

Extinguishment - The cessation of combustion (not to be confused with blackout, which is the cessation of visible flaming).

Failed Barrier - When a barrier has "failed" in a SAFE computer model run, EB is assumed in the adjacent compartment if that room is not already burning. The failure mode is thermal (T-bar) if the barrier's T-bar > D-bar; conversely if D-bar is >= T-bar, the failure mode is D-bar.

FAL - Frequency of Acceptable Loss. The frequency with which a compartment can sustain a given Magnitude of Acceptable Loss (MAL). The FAL and MAL together establish the fire safety objectives (FSOs) for a given compartment. See "MAL" and "FSO."

FFS - Fire Free State. The status of a compartment relative to fire before ignition has occurred.

Fire - Combustion. Usually destructive and undesirable in a ship. See "Combustion" and "Pyrolysis."

Fire Growth Model - One of 16 models of fire growth defined in SAFE that may be selected by the user to describe the characteristics of the fuel load in a compartment. The fire growth model determines the fire growth coefficient, alpha, and the maximum heat release rate, Qmax. See "Alpha" and "Qmax."

Fire Path - The sequential spread of fire from the compartment of origin through a failed barrier into an adjacent compartment, then through another barrier into another space and so on until the fire is limited. Multiple fire paths occur when failure of more than one barrier in a compartment permits the fire to spread into multiple compartments.

Fire Safety System - A term used to address the overall performance of a ship as it relates to fire safety. It considers the ship as a whole and accounts for such things as compartment geometry, construction, fuel type and load, automatic detection and monitoring systems, ventilation, and fire protection systems.

Flashover - A phenomenon characteristic of compartment fires denoted by the rapid and sudden propagation of flame through the unburned gases and vapors collected at the top of the enclosure. Flashover is invariably accompanied by full room involvement (FRI). FRI conditions are untenable for humans.

FLLR - Flammable Liquid Line Rupture. A scenario used in SAFE to model a class B spray fire. The key user defined variables include the amount of fuel due to the rupture that is added to the compartment's fuel load, the room of origin, and its associated FRI time and I value.

Frequency of EB (losses per compartment year) - A frequency based on historic fire casualty data compiled from data provided by the U.S. Naval Safety Center and the Coast Guard's MISREP mishap reporting system.

FRI - Full Room Involvement - The point in the fire growth curve when the temperature in a compartment has increased 500° C above ambient. FRI conditions include surface burning of all combustibles and survival for unprotected personnel is not possible.

FRI Time (minutes) - The elapsed time from EB to FRI calculated in SAFE using the Peatross/Beyler algorithm. See "FRI."

FSAC - Fire Safety Analysis of Cutters. Project sponsored by the U.S. Coast Guard to analyze fire safety on cutters 180' and greater in length.

FSOs - Fire Safety Objectives - Performance standard, ideally established by cognizant authorities, for a compartment accounting for mission protection, property protection, and life safety. The SFSEM is designed to analyze, quantify, and compare the ship's performance as a fire safety system to achieve the established FSOs on a compartment basis. The FAL and MAL together establish the FSOs for a given compartment. See "FAL" and "MAL."

Fuel-Controlled Burning - When sufficient ventilation is available, fuel controlled burning will occur. The fire is limited by the fuel surface and fuel quantity available for combustion. See "Ventilation-Controlled Burning."

Fuel Load (BTUs/sq ft) - The total heat energy available for release from combustible materials in a compartment. In SAFE, fuel loads are expressed as fuel load density, where the total fuel load in a compartment is divided by the compartment area. Fuel loads are entered in SAFE for cellulosics, plastics, and petroleum-based flammable liquids. Cellulosics and plastics are entered in lbs/sq ft, while flammable liquids are entered as gallons. The heat energy content of cellulosics is approximately 8,000 BTUs/lb; plastics and flammable liquids are approximately 16,000 BTUs/lb (flammable liquids are assumed to weigh 8 lbs/gallon).

FY - Fiscal Year - (For example, FY96 is Oct. 1, 1995, to Sept. 30, 1996).

Halon - Halogenated Hydrocarbon. A firefighting agent particularly effective against all classes of fires. Halon is presently banned from further production in accordance with the Montreal Protocol due to its atmospheric ozone-depleting characteristics.

Hatch - An opening through a deck providing access to a compartment. If a hatch greater than or equal to 400 square inches is open, it is equivalent to a durability failure of the associated barrier.

Heat Energy Impact (HEI) (kBTUs/sq ft) - The thermal heat flux to which the barrier is subjected during a fire. See "Pre-FRI Heat Release Rate" and "Post-FRI Heat Release Rate."

I-Curve - The resulting curve when I values for a compartment fire reaching the enclosure point, the ceiling point, and the room point are plotted on a graph with probability of flame limitation on the ordinate axis (logarithmic scale), with the origin at the top left, and the area of fire involvement on the abscissa axis (linear scale). See "I-Value."

Ignition - Point in the fire growth curve that denotes the beginning of pyrolysis of combustible fuel.

Ign Mode - Ignition Mode. In SAFE, one of three ways a compartment can reach EB: orig (as room of origin), therm (due to a thermal [T-bar] failure), or dur (due to a durability [D-bar] failure).

Intermediate Barrier Value (IBV) - The probability that the barrier will be successful in limiting the spread of fire. In SAFE, IBV is calculated as IBV = P(FPC)*P(BF), where P(FPC) is the probability of failure in limiting the fire in the previous compartment (1-Cum L in the previous compartment) and P(BF) is the probability of this barrier failing to limit the fire (1- [T-bar + D-bar]).

I-Value (%) - The probability that the fire will self-extinguish at some point between EB and FRI, given that the fire was not extinguished by automated systems or by manual firefighting efforts. Each compartment is assigned three I-values: the probability of flame limitation given EB in the room of origin, the probability of flame limitation given EB has occurred in the room as a result of a thermal (T-bar) failure of a barrier, and the probability of flame limitation given EB has occurred in the room as a result of a durability (D-bar) failure of a barrier. In SAFE, these values are abbreviated OI, TI, and DI, respectively.

L-Curve - A graph that plots the cumulative probability of limiting the flame on the Y axis against time or some other suitable parameter on the X axis, such as the number of rooms in a fire path or the deck area of a particular compartment. Convention calls for plotting 0 as the probability of limiting the flame at the top of the Y axis and 100% as the probability of limiting the flame on the X axis. See “cum-L.”

L-Value (%) - The probability that a fire will be limited in a given compartment calculated from the I, A, and M values for that compartment.

MAL - Magnitude of Acceptable Loss **-** The severity of damage that can be tolerated in a compartment. FAL and MAL together establish the FSOs for a given compartment**.** See “FAL” and “FSOs.”

Material ID - A three-character identifier to describe one of a compartment’s barriers selected from the catalog of available barrier materials.

M-Curve - The resulting curve when M-values for increasing areas of a compartment are plotted on a graph with probability of flame limitation on the ordinate axis (logarithmic scale) with the origin at the top left and the deck area of the compartment on the abscissa axis (linear scale). See “M-Value.”

M Value (%) - The probability that manual firefighting efforts will successfully extinguish the fire before FRI occurs given that the fire did not self-terminate and was not extinguished by automated fire protection systems. Each compartment is assigned three M-values: the probability of flame limitation given EB in the room of origin, the probability of flame limitation given EB has occurred in the room as a result of a thermal (T-bar) failure of a barrier, and the probability of flame limitation given EB has occurred in the room as a result of a durability (D-bar) failure of a barrier. In SAFE, these values are abbreviated OM, TM, and DM, respectively.

NFTI - Naval Firefighting Thermal Imager. A hand-held device used to locate the source of flames in a compartment by sensing the infrared thermal emissions in the space.

Nonstandard Scenario - Similar in all respects to a Standard Scenario except that it considers reduced levels of available fire protection systems.

NSTM - Naval Ship's Technical Manual. A set of regulations and guidelines issued by the U.S. Navy and frequently cited in U.S. Coast Guard regulations.

OBA - Oxygen Breathing Apparatus. A self-contained device that supplies oxygen to facilitate firefighting in untenable atmospheres.

One-Shot Halon System - A total flooding system with the capability to completely flood the protected space one time with the required concentration level of Halon 1301.

Overhead - The equivalent in a ship to a ceiling in a building. Overheads can be continuous or stepped, insulated or bare. They can be constructed from steel, aluminum, or a composite material such as Nomex or Celotex. They can be covered with sheathing, insulation, or both on one side and covered with carpet, tile, or a poured floor such as terrazzo on the other. Together with bulkheads, they serve to segment the ship into various compartments.

P-250 - A portable gasoline-powered pump used for firefighting and dewatering.

Passive Fire Protection - Fire protection features designed to limit flame movement by their presence alone. Barriers are the best example of passive fire protection; intumescent coatings, fire doors, fire insulation, fuel load distribution, and insulation of hot surfaces are other examples. See "Active Fire Protection."

Peatross/Beyler Algorithm - The algorithm used in SAFE, version 2.2, to calculate FRI-time for compartment fires. Primary variables include heat release rate, heat loss through the boundaries, and the incoming air. See "FRI-Time."

Percent Monitored At Sea (%) - An estimate of the percentage of time around the clock while a ship is underway that a compartment is monitored to detect the presence of smoke and flames. Both personnel and fire/smoke/heat detectors can monitor a compartment.

Percent Monitored In Port (%) - An estimate of the percentage of time around the clock while a ship is in port that a compartment is monitored to detect the presence of smoke and flames. Both personnel and fire/smoke/heat detectors can monitor a compartment.

Petrochemicals - One of two classifications of fuel on ships. Petroleum-based chemical products are characterized by having twice the heat energy per pound than cellulosics type of fuel. Examples of petrochemicals include flammable liquids and polymeric materials. See "Fuel Load and Cellulosics."

PKP - Potassium Bicarbonate. A dry chemical firefighting agent frequently used in portable fire extinguishers. The only authorized dry chemical portable fire extinguisher permitted on board Coast Guard Cutters.

Plan ID - A unique identifier for compartments as used in the Booklet of General Plans and other ship's drawings. The four fields that make up the identifier are deck number, forward frame number, relationship to the centerline (1 for starboard, 2 for port, 0 for centerline), and compartment use indicator. Examples are 3-66-0-E and 01-40-2-L.

Post-FRI Heat Release Rate (kW) - The rate that heat is released from the burning fuel in a compartment during the fully developed fire realm and calculated in accordance with the following expression: $Q = 1500 * A*H^{0.5}$. In SAFE, the ventilation factor, $A*H^{0.5}$, takes into account the height and area of all ventilation openings. Open doors, hatches, windows, etc., are assumed to be ventilation openings. The numerical coefficient, 1500, assumes stoichiometric burning conditions.

Pre-FRI Heat Release Rate (kW) - The rate that heat is released from the burning fuel in a compartment during the fire growth realm and calculated according to: $Q = \text{Alpha} * t^2$. The heat energy produced is used as a key variable in the Peatross/Beyler algorithm for calculating compartment fire temperatures; when the temperature exceeds ambient by 500° C, full room involvement (FRI) is assumed to exist in the compartment.

Pyrolysis - The conversion of solid fuel into flammable vapor through the application of heat.

Qmax - The maximum heat release rate value applied on a compartment-by-compartment basis. Qmax is the upper limit for Q in the Peatross/Beyler algorithm and is a function of the fire growth model. See "Fire Growth Model."

Radiation Point - The transition point between smoldering combustion and the point where a fire grows proportionally to the square of time. This point (beginning of exponential fire growth) is also referred to as Established Burning (EB), since this is the point where radiational feedback to the fuel bed becomes the predominant mode of heat transfer.

Relative Frequency of Acceptable Loss/Fire Free State - Relative Frequency of Acceptable Loss of a compartment given Fire Free State, calculated in SAFE by summing the probabilities of a target compartment or set failing to meet its FSOs over all fire paths, from all possible rooms of origin, multiplied by the frequency of EB in each room of origin.

Residual Heat Transfer (%) - The percentage of remaining thermal energy transferred from a burning compartment to an adjacent compartment due to a D-bar failure of a barrier. This transfer does not occur if the adjacent compartment is at full room involvement. This parameter is a function of the barrier material and can be found in the catalog of available barrier materials.

RLF - Relative Loss Factor - RLFs are calculated in SAFE as a means of assessing whether a target compartment or set meets FSOs. A Relative Loss Factor > 1 indicates that a target compartment has failed to meet its FSOs. This factor is determined by multiplying the target's Relative Frequency of Acceptable Loss given Fire Free State of the target in failures/year (calculated during a given run of SAFE) by the assigned frequency of acceptable loss in years. A target is considered lost if its level of fire involvement in a given path exceeds the level specified by its MAL rating.

Room of Origin - The compartment in a fire path where EB first occurs.

Room Point - The point in the growth of a compartment fire where flames fully involve the compartment. See "Full Room Involvement."

SAFE - Ship Applied Fire Engineering - The computerized implementation of the SFSEM. SAFE is actually an integrated series of computer programs utilizing AutoCAD and the INFORMIX relational data base management system

Scenario - A situation defined by the user before executing a SAFE probabilistic model run. Such parameters as run time, ship location, material condition of readiness, and firefighting configuration are specified.

SCFP - Small Cutter Fire Protection. Project sponsored by the U.S. Coast Guard to analyze fire safety on cutters less than 180' in length.

SFSEM - The Ship Fire Safety Engineering Methodology. A probabilistic-based risk analysis methodology used to analyze all aspects of the ship's performance in response to a fire compared to preestablished FSOs.

Shell Plating - The ship's hull consisting of the underwater body and the freeboard Main Deck and below. The ship's superstructure is above the Main Deck. Shell plating can be steel or aluminum.

SHIPALT - Ship Alteration. A document that describes an authorized change to the configuration, compartmentation, or other major alteration to a ship. The purpose of SHIPALTS is to standardize the configuration of all ships in a class.

Ship Location - A ship is either "at sea" or "in port" for the purpose of setting up a model run in SAFE.

SOLAS - Safety of Life at Sea. An international convention, prompted by the TITANIC disaster (amended several times since), that establishes international regulations for building ships to ensure passenger safety.

Standard Scenario - Scenarios that describe a ship's location and material condition of readiness with passive automated and manual fire protection capabilities in effect. Since this describes a ship under normal operating conditions, these scenarios are referred to as standard scenarios. See "Nonstandard Scenario."

Stepped Deck - That portion of a deck that is not in the same horizontal plane as the majority of the deck.

Stoichiometric - A term that describes ideal burning, which assumes there is sufficient oxygen to ensure 100% combustion of available fuel. Stoichiometric burning produces the hottest fire temperatures; therefore, sufficient ventilation to produce stoichiometric conditions is assumed in the SFSEM where fire protection systems should be designed for worst case conditions.

Superstructure - The ship's structure above the Main Deck. The superstructure can be steel or aluminum.

T-Adjust (%) - A value that can range from 0% to -99% that is applied to the T-bar value of a specified barrier to account for cracks or other flaws that would reduce its ability to resist a thermal or hot spot failure. An open door or window is not considered a derating of the barrier.

Target - A compartment or set of compartments that are analyzed in a probabilistic model run for the frequency and magnitude of fire loss due to fires started in every possible room of origin. A target set of compartments may be selected because they contain components necessary to perform a ship's mission. In this manner the likelihood of mission failure can be ascertained.

T-bar (%) - The probability of a thermal failure of a barrier which would permit a small, hot spot ignition in the adjacent compartment.

Therm IAM (%) - The probability of terminating a fire originating in a compartment due to a thermal barrier failure. The probability is calculated from a combination of the I, A, and M curves for that room. If the room is a room of origin, Therm IAM is not applicable.

Two-Shot Halon System - A total flooding system with the capability to completely flood the protected space two times with the required concentration level of Halon 1301. This system is designed such that each shot of Halon is released from a different location in the vessel.

USCGC - United States Coast Guard Cutter.

Vent Area (sq in) - The sum of all the ventilation openings in a compartment, excluding doors and hatches but including ventilation grates in a door. Used to calculate the post-FRI heat release rate. See "Post-FRI Heat Release Rate."

Vent Height (in) - The average of the vertical height of all vent openings in a compartment. The height of the compartment itself is used for horizontal vents.

Ventilation Controlled Burning - When insufficient ventilation is available, ventilation controlled burning occurs. The fire is limited by the air supply available for combustion. See "Fuel Controlled Burning."

Ventilation Factor - A factor, $A*H^{0.5}$, that describes the primary variables in the post-FRI heat release rate calculation in SAFE. These variables are the area and height of the ventilation opening(s) in a compartment. In compartments with multiple vents, areas are summed and heights are averaged.

WMEC - U.S. Coast Guard Medium Endurance Cutter.

XRAY, YOKE, and ZEBRA - Material Conditions of Readiness. Successively increasing levels of watertight integrity for controlling damage. At each level, additional access closures, valves, and fittings are required to be closed to limit fire and flooding.

Zero-Strength Barrier - An imaginary boundary used to model extremely long passageways and multiple-deck compartments. The barrier is presumed to have no thermal resistance.

1. INTRODUCTION

1.1 BACKGROUND

The U.S. Coast Guard operates a large fleet of Medium Endurance Cutters to conduct various Coast Guard missions including Search and Rescue, Maritime Law Enforcement, and Defense Operations. The fleet includes 33 cutters primarily in the 210’ and 270’ WMEC Medium Endurance Cutter classes. These cutters are equipped with flight decks, JP-5 refueling machinery, and other equipment to support helicopter operations. Typical patrols may extend up to three weeks underway, although two-week patrols are more common. The normal crew size on a 210’ WMEC is 75 persons; this class of cutter is not considered to be minimally manned.

The Coast Guard commenced the Paragon Project to more effectively and efficiently operate a 210’ WMEC in all mission areas, with an eye cast toward opportunities for crew-size reduction. The USCGC DEPENDABLE (and crew) was selected as the test vessel to evaluate this new operational philosophy. The Coast Guard is evaluating all aspects of operating DEPENDABLE with a reduced crew including effects on fire safety, watchstanding, maintenance, and mission performance. It is desired to evaluate the difference in fire protection levels on board pre-Paragon and post-Paragon operating cutters to ensure that an acceptable level of fire safety is achieved in both configurations.

The Coast Guard previously initiated the Small Cutter Fire Protection (SCFP) project to thoroughly analyze the fire safety of 10 classes of small cutters (less than 180' in length) and produce a tailored fire protection doctrine for each. The scope of the SCFP project included the 82' Point Class Patrol Boat, 110' Surface Effect Ship, 110' Island Class Patrol Boat, 65' Harbor Tugboat, and several classes of buoy tenders (including the 175' WLM [R] class) in the Coast Guard fleet. The Fire Safety Analysis of Cutters (FSAC) project was initiated by the Coast Guard to thoroughly analyze the fire safety of large cutters. The scope of the FSAC project included cutters 180’ and greater, such as the 180’ Seagoing Buoy Tender, 210’ and 270’ Medium Endurance Cutters.

The technical approach in the SCFP and FSAC projects specified the use of the Ship Fire Safety Engineering Method (SFSEM) as the analytical tool to evaluate shipboard fire safety. The SFSEM is a probabilistic-based risk analysis methodology that provides an integrated framework to account for all relevant aspects of shipboard fire protection. The <u>Theoretical Basis of the Ship Fire Safety Engineering Method</u> [1] provides a comprehensive discussion of the SFSEM. The SFSEM is designed to evaluate the ship's performance compared to preestablished fire safety objectives (FSO). The methodology quantifies the contribution of passive and active fire protection systems, thus it provides a means for analyzing and comparing hypothetical design alternatives to improve the overall fire protection on the cutter as necessary. SAFE, version 2.2, is a series of integrated computer programs that automate the numerous calculations required. In addition, various output options are available in SAFE that permit a detailed analysis of compartment and barrier performance. Appropriate documentation is available in the <u>SAFE User Manual, version 2.2</u>. [2]

As noted in the final report for the SCFP project, the following features of the SFSEM have been clearly demonstrated: [3]

- Utility to analyze existing ships, as well as proposed designs

- Ability to identify problem compartments that fail to meet fire safety objectives
- Capability to analyze the effectiveness of hypothetical design alternatives

Therefore, the SFSEM was specified as the analytical tool to evaluate the fire safety of the USCGC DEPENDABLE prior to the Paragon project and subsequent to reducing the crew and other changes associated with the Paragon project. The SFSEM/SAFE is an ideal tool for this analysis, because if any adverse changes to the fire safety levels are noted, SAFE could be used to evaluate potential methods to restore fire safety to pre-Paragon levels.

1.2 SCOPE

The scope of this project involves analyzing the fire safety of the CGC DEPENDABLE. The analysis compares the fire safety levels before and after the changes associated with the Paragon project were implemented on the cutter. The changes associated with Paragon project include:

- An improved fire detection system that is fully addressable
- Installation of fixed surveillance cameras
- An improved internal communications system
- A reduced in-port duty section when the cutter is in homeport
- Utilization of a rapid response team concept

Complete details concerning changes associated with the Paragon Project are discussed in section 4.1 of this report.

The primary objective established for this project is to evaluate and compare the fire safety of the CGC DEPENDABLE before and after changes associated with the Paragon Project were implemented. The fire safety analysis of the DEPENDABLE prior to Paragon changes is referred to in this report as the baseline analysis. These results are discussed in Section 3 of this report and should be comparable to the fire safety analysis results of other 210' WMEC class cutters. The fire safety analysis of post-Paragon conditions for DEPENDABLE are discussed in Section 4 of this report. Due to different operating conditions, there are two baseline conditions discussed in Section 3 and three post-Paragon conditions discussed in Section 4 as follows:

- Baseline at sea. Fire scenarios assume that the full crew complement of 75 persons are on board, awake, and alert. Two repair parties are fully manned when the Bridge announces "general emergency" or "fire." The fire detection system is not capable of distinguishing among compartments comprising a zone. Wireless communications devices are not available; crew members must use existing internal communications systems.
- Baseline in port. Fire scenarios are assumed to occur at night when the normal duty section is on board. In addition, a minimum number of other personnel may also be on board at night in port. Since this cutter is not minimally manned, the normal in-port duty section is assumed capable of manning a single repair party with the same number of crew members as at-sea conditions. Wireless communications devices are not available; crew members must use existing internal communications systems.

- Post-Paragon at sea. Fire scenarios assume that the reduced crew complement of 65 persons are on board, awake, and alert. One repair party is fully manned when the Bridge announces "general emergency" or "fire." A four-person rapid response team is deployed immediately to the scene of the fire. They do not dress out in firefighting ensembles, and they pick up portable extinguishers while proceeding to the scene. The new fully addressable fire detection system and surveillance cameras are operable, but the laptop computer and interface to the system are not operable. The wireless communications devices are used by all crew members.
- Post-Paragon in homeport. Fire scenarios are assumed to occur at night with a reduced duty section on board. The reduced duty section consists of five persons. The vessel must be in a cold-iron status with minimal operating machinery. It is also assumed that assistance is available from other vessels in the cutter's homeport as well as from the local city fire department. A four-person rapid response team is deployed immediately to the scene of the fire. They do not dress out in firefighting ensembles, and they pick up a portable extinguisher while proceeding to the scene. The new fully addressable fire detection system and surveillance cameras are operable, but the laptop computer and interface to the system are not operable. All crew members use the wireless communications devices.
- Post-Paragon in port away from homeport. Fire scenarios are assumed to occur at night when the normal duty section is on board. In addition, a minimum number of other personnel may also be on board at night in port. The normal in-port duty section is assumed capable of manning a single repair party with the same number of crew members as at-sea conditions. A four-person rapid response team is deployed immediately to the scene of the fire. They do not dress out in firefighting ensembles and they pick up portable extinguishers while proceeding to the scene. The new fully addressable fire detection system and surveillance cameras are operable, but the laptop computer and interface to the system are not operable. All crew members use the wireless communications devices.

Even though only some of the features of the new fire detection and monitoring system were operable and thus analyzed, the remaining features will further improve the fire safety of the cutter. Therefore, the results of this analysis are considered conservative.

1.3 TECHNICAL APPROACH

This project was organized into five sequential phases:

1. Conduct a ship visit of the CGC DEPENDABLE, Portsmouth, VA.
2. Collect factual input data and develop subjective input data needed to run SAFE.
3. Analyze fire safety of DEPENDABLE based on pre-Paragon (baseline) conditions using the SFSEM/SAFE.
4. Analyze fire safety of DEPENDABLE based on post-Paragon conditions using the SFSEM/SAFE.
5. Document results in this final report.

The first phase involved a ship visit from 30 September to 3 October 1997. During this visit, factual and subjective information was collected concerning the characteristics of the cutter that affect fire safety. This phase also included modeling the compartmentation in AutoCAD as a necessary prerequisite for using the SFSEM/SAFE. The second phase involved developing subjective input data, such as fire safety objectives and probabilities of flame termination, and documenting the factual input data, such as fuel loads and ventilation details. After all input data was entered into SAFE, a thorough review of the baseline fire safety levels of the DEPENDABLE (pre-Paragon) using the SFSEM/SAFE was performed in phase three. The individual target option provided relative loss factors that are a relative comparison of compartment loss compared to the fire safety objectives established for each compartment. Phase four involved analyzing post-Paragon conditions on DEPENDABLE. A one-day ship visit on 22 October 1998 was conducted to collect data about the changes implemented as a result of the Paragon project. Results of this analysis were compared with the baseline results to determine the effect of operating the vessel with a reduced crew and other changes implemented in the Paragon project. Finally, the results of the entire study were documented in the final technical report compiled in phase five.

1.4 FIRE SAFETY ANALYSIS PROCEDURE

The fire safety analysis of Coast Guard cutters typically compares the predicted loss potential for each compartment with the fire safety objectives established for each compartment in the cutter under evaluation. In this project, the comparison was made for the CGC DEPENDABLE under pre-Paragon and post-Paragon conditions/configurations. The SFSEM/SAFE analysis of the pre-Paragon conditions (considered the "baseline") is described in Section 3 of this report. The SFSEM/SAFE analysis of the post-Paragon conditions is described in Section 4 of this report

The following nine-step procedure, discussed briefly in the following sections, used to conduct the fire safety analysis of the CGC DEPENDABLE was adapted from the detailed fire safety analysis procedure used in the SCFP and FSAC projects:

1. Model the cutter in AutoCAD.
2. Load data base with ship's geometry.
3. Conduct ship visit.
4. Load input values into SAFE.
5. Calculate FRI times and post-FRI heat release rates.
6. Run SAFE on baseline (pre-Paragon) conditions.
7. Run SAFE on post-Paragon conditions.
8. Compare fire safety analysis results.
9. Document results.

1.4.1 MODEL THE CUTTER IN AUTOCAD

The general arrangement drawings provided by the Coast Guard are converted to AutoCAD before the ship visit is conducted. Zero-strength barriers are used to divide long compartments, such as passageways or compartments that span multiple deck levels. Other modeling techniques are described in the SAFE User Manual. [2]

1.4.2 LOAD DATA BASE WITH SHIP'S GEOMETRY

The simplified, yet accurate, representation of the ship's geometry created in AutoCAD is utilized by the connectivity generator in SAFE to produce a listing of all compartments on the cutter. Also produced is a listing of each compartment's barriers and individual connections to other compartments or to the weather. Once these lists have been verified for accuracy, they are loaded into SAFE's data base and ship visit forms are produced.

1.4.3 CONDUCT SHIP VISIT

The SFSEM/SAFE requires an extensive amount of data to facilitate an analysis of the cutter's fire safety. Preprinted ship visit forms ensure that the information concerning fuel loads, compartmentation, ventilation, fire safety objectives (FSOs), and other required data is collected in an efficient manner. This information is also used by the engineer/analyst to temper the engineering judgment required to develop the probabilistic values entered into SAFE. The accuracy of the fire safety analysis is directly proportional to the quality and completeness of the information collected during the ship visit and from written documentation, drawings, and other information sources.

1.4.4 LOAD INPUT VALUES INTO SAFE

This step includes refining the ship's geometry with any new information gathered during the ship visit, determining all required fire parameters, performing the data entry of the information on the ship visit forms, and verifying the accuracy of the entered data. The values now in the data base comprise the "baseline data set" for the ship. This baseline data set permits discrimination between the pre-Paragon data sets and the post-Paragon data sets (which are created in a subsequent project phase).

1.4.5 CALCULATE FRI TIMES AND POST-FRI HEAT RELEASE RATES

Flashover is the sudden propagation of flames through the unburned gases and vapors collected at the top of the compartment. Flashover invariably leads to full room involvement (FRI) conditions where the majority of combustible surfaces are burning and conditions for life are untenable. FRI time, or the elapsed time from EB to Full Room Involvement (FRI), is a very important parameter in fire growth. After all input values have been assigned, FRI times and post-FRI heat release rates are calculated for each compartment. FRI times may be reviewed and adjusted, or input values used to calculate FRI time may be adjusted and FRI time recalculated. FRI times are calculated in SAFE in accordance with the Peatross/Beyler algorithm. [4] Basically, this algorithm calculates the time in minutes for the temperature in a compartment to rise 500° C above ambient.

The variables in the post-FRI heat release rate calculation are included in the ventilation factor: $A*H^{0.5}$. This factor takes into account the height and area of a single vertical ventilation opening, which is providing natural (unforced) ventilation. The coefficient for this variable is based on the worst-case assumption of stoichiometric combustion. Some ship compartments are served by multiple vents and frequently use forced ventilation through horizontal vents; thus, determining vent opening height becomes problematic. The Theoretical Basis of the SFSEM provides an explanation how SAFE deals with multiple and horizontal vent openings. [1]

1.4.6 RUN SAFE ON BASELINE (PRE-PARAGON) CONDITIONS

Once the data base has been loaded with all required input, the probabilistic model is run on the baseline data set to establish the baseline fire safety levels of the cutter. Several parameters have to be specified in order to run the model. These parameters are specified in "scenarios" and include material condition of readiness (XRAY or YOKE), ship location (in port or at sea), firefighting configuration (passive [I], automated [A], and/or manual [M]), simulation run time (in minutes), and barrier failure criteria (best case or worst case). The Theoretical Basis of the SFSEM and the SAFE User Manual, Version 2.2, provide detailed explanations for these parameters and scenarios. [1, 2]

The objective of the baseline fire safety analysis is to quantify the level of fire safety prior to implementing changes associated with the Paragon project. This is accomplished by comparing the results with fire safety objectives established for the cutter. The baseline analysis is designed to identify compartments that fail to meet FSOs (or significantly exceed their FSOs) so that attention can be focused on these compartments.

The results of using the individual target option with the standard scenarios on the baseline data set are carefully examined to determine how well the ship performs as a fire safety system in response to a fire. This is accomplished by examining relative loss factors (RLF) for "target" compartments. RLFs greater than 1.0 indicate that the target compartment failed to meet the FSOs established for that compartment and an improvement in fire protection is needed. A target compartment with a RLF equal to 1.0 indicates that the compartment exactly meets its FSOs. A target with a RLF less than 1.0 indicates that the compartment exceeds its FSOs and a reduction in fire protection may be warranted.

The results from the individual target option focus on the target compartments, which do not meet their FSOs. These results do not provide any insight as to the primary sources of the fires that ultimately caused the loss of the targets. Determining the source or cause of each failed compartment may involve running the probabilistic model with different output options, such as the barrier or path options. For example, the detailed reports from the target option, barrier option, and path option may yield information that many of the fire paths that ultimately involve the target compartment actually originate in another compartment. Thus, improving the fire protection in the appropriate room of origin may improve the results in the target compartment as well as the room of origin. If all compartments exceed FSOs, insights gained by running the barrier option and path option are not required.

1.4.7 RUN SAFE ON POST-PARAGON CONDITIONS

The baseline data set is adjusted as needed to account for any changes implemented in conjunction with the Paragon project. For example, the new detection and monitoring system should improve the performance of the cutter as a fire safety system. Since the rapid response team (RRT) deploying to the scene of the fire arrives quickly and has the benefit of knowing a more localized estimate of the room of origin, the RRT should be able to attack the fire when it is smaller in size and thus easier to extinguish. Moreover, in compartments with installed automated fire protection systems, the RRT should be able to activate the system earlier in the fire growth period, thus improving the probability of flame termination by automated means. A reduced in-port duty section in homeport does not permit manning a full repair party, which reduces the onboard, initial firefighting capability. The manual firefighting effectiveness of the post-Paragon DEPENDABLE is affected by all the changes associated with this program. Since some of these changes increase fire safety and others decrease fire safety, the SFSEM/SAFE provides a way to analyze the combined effect of all changes. In general, the baseline data set is only changed to directly account for changes implemented by the Paragon project. To ensure the ability to compare results accurately, it is particularly important that the fire safety objectives used in the baseline or pre-Paragon data set are those used in the post-Paragon data set.

1.4.8 COMPARE FIRE SAFETY ANALYSIS RESULTS

This step involves comparing the results of running SAFE with the target option on both baseline and post-Paragon data sets to the established FSOs. A comparison of results will indicate whether the overall fire safety levels have either increased or decreased as a consequence of the Paragon project. In addition, the goal of this comparison is to identify compartments that fail to meet FSOs. If any compartments fail to meet FSOs, the SFSEM/SAFE may be used to study hypothetical changes that could improve the fire safety of those compartments to acceptable levels. This may involve running other options available in SAFE, such as the barrier and path option.

It is feasible to compare the fire safety levels of the DEPENDABLE with other classes of Coast Guard cutters that have been analyzed using the SFSEM/SAFE. However, comparison of DEPENDABLE with other cutter classes is outside the scope of this project.

1.4.9 DOCUMENT RESULTS

The final report documents the results of this study. Reports from SAFE that were generated are included in the appendices as supporting data. Graphic reports from SAFE (including color graphics) are available outputs from SAFE. For example, SAFE can generate deck plans that portray compartments that fail to meet FSOs in red, while compartments colored yellow, green or blue are progressively “safer.”

1.5 ORGANIZATION OF REPORT

Section 2 of this report discusses historical fire records that pertain to U.S. Coast Guard cutters, as well as the process used to establish the frequency of EB in various types of compartments. The results of the baseline fire safety analysis of the DEPENDABLE are discussed in Section 3. Section 4 presents the results of the analysis of post-Paragon conditions as a result of the changes implemented in the Paragon project. Section 5 summarizes the conclusions and recommendations that were developed as a result of the fire safety analyses accomplished in this project. Appendix A presents plan views of all decks in the USCGC DEPENDABLE. Appendix B includes the documentation of all input data that comprises the baseline data set. Appendix C contains the detailed baseline fire safety analysis results generated by running the individual target option. Appendix D documents the SAFE input data and the target option output results from the analysis of post-Paragon conditions. Appendix E contains the methodology used to establish probabilities of flame termination in a consistent manner.

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2. HISTORICAL RECORDS OF FIRE

2.1 FREQUENCY OF ESTABLISHED BURNING

Fire safety analyses of Coast Guard Cutters to date have utilized historical records to establish the frequency of established burning (EB), since adequate data from the U.S. Naval Safety Center and U.S. Coast Guard Headquarters is available for each type of compartment aboard a cutter. Military ships, including Coast Guard Cutters, are required to report all fires that result in damage or personal injury. This provides the opportunity to utilize historical records to determine the frequency of EB.

Historical reports of fires on all classes of Coast Guard Cutters were obtained from the Commandant (G-KSE-4), U.S. Coast Guard, for the period FY87 to FY91. This data was combined with data received from the U.S. Naval Safety Center on 21 classes of large naval vessels during the period 1975 through 1986 to refine the reported fire frequencies. For the purposes of the SFSEM, similar compartments were grouped by compartment use indicator (CUI). CUI categories were adapted from the standard nomenclature used by the Coast Guard and Navy to identify compartment usage. Some CUIs were further subdivided in order to permit a more accurate assignment of reported fire frequency. Based on experience, it is estimated that approximately half of all fires that reach EB do little or no damage to the vessel and result in no injuries to personnel; thus they may go unreported. As a result, the "reported frequency of EB" based on historical data is doubled and called "adjusted fire frequency" to account for unreported fires. The number of fires reported and adjusted fire frequency values from the combined Navy and Coast Guard data are shown in Table 2.1, grouped according to CUI.

The adjusted fire frequencies for Main Propulsion Mechanical (EM) and Emergency Auxiliary Generator Rooms (QE) compartments are much greater than for other compartments. This fact has a substantial impact on the results of a fire safety analysis using the SFSEM.

Table 2.1 Fire Frequency Data

Type of Compartment	Compartment Use Indicator (CUI)	Number of Fires Reported	Adjusted Fire Frequency (1) (Fires per Compt Year)
Cargo Hold	AA	0 (2)	0.0001 (3)
Gear Locker	AG	19	0.0010
Refrigerated Storage	AR	3	0.0009
Storeroom	AS	34	0.0009
Ship Control Area	C	4	0.0012
Main Propulsion Electrical (4)	EE	7	0.0031
Main Propulsion Mechanical	EM	148	0.0272
Fuel Oil, Lube Oil Tank	F	0 (2)	0.0001 (3)
JP-5 Fuel Tank	J	0 (2)	0.0001 (3)
Hazardous Material Storage	K	4	0.0013
Berthing Space	L1, L2, L5	20	0.0008
Wardroom, Mess, Lounge Space	LL	7	0.0008
Medical, Dental Space (4)	LM	0	0.0001
Passageway, Staircase, Vestibule	LP	3	0.0001
Sanitary Space	LW	4	0.0002
Explosives Storage	M	1	0.0001
Auxiliary Machine Space (4)	QA	89	0.0029
Emergency Aux. Generator Room (4)	QE	23	0.0204
Fan Room	QF	7	0.0004
Galley Pantry, Scullery	QG	13	0.0026
Helicopter Hangar	QH	3	0.0036
Laundry	QL	5	0.0031
Office Space (4)	QO	5	0.0004
Shops, Labs	QS	15	0.0018
Trunk, Hoist, Dumbwaiter	TH	0 (2)	0.0001
Stack, Uptake	TU	5	0.0013
Void, Cofferdam	V	1	0.0001 (3)
Water, Peak, Ballast Tank	W	1 (2)	0.0004

NOTES:

1. Taken as twice the reported fire frequency
2. Based on 1986 - 1991 USCG data only. (All other numbers of fires based on both USN and USCG data.)
3. Default value used in cases where no fires have been reported or when calculated adjusted frequency is below 0.00005
4. New compartment types added since analysis of first three small cutters in the SCFP project

2.2 HISTORICAL RECORDS OF FIRES ON COAST GUARD CUTTERS

The Coast Guard MISREP data base was researched for historical records of reported fires by all Coast Guard Cutters during the period FY87 through FY91. Commandant (G-KSE-4) data included reports of 29 fires and 2 explosions over the 5-year period on cutters that represent 95% of the Coast Guard fleet. Three of the 31 fires/explosions (10%) occurred in 378' High Endurance Cutters; 13 fires/explosions (42%) occurred in 210' and 270' Medium Endurance Cutters, 180' Medium Endurance Cutters, and 140' Icebreaking Tugboats; the remaining 15 (48%) occurred in small cutters ranging from 65' Harbor Tugboats to 110' Island Class Patrol Boats and Construction Tenders.

The data provided by the Commandant (G-KSE-4) were also analyzed to obtain such information as the frequency that arson is a problem, the frequency of fires that spread to other compartments from the room of origin, the class of fires that most frequently occur, and the type of compartment where high-dollar-loss fires occur. This analysis revealed the following:

- The breakdown of the 29 fires shows that 18 were class A, 4 were class B, 5 were class C, and there were 2 unknown class fires.
- Most reported fires were relatively minor. Only 7 fires resulted in damage exceeding $1,000. There were no deaths, 6 minor injuries, and 25 fires with no injuries.
- Arson was not considered a factor in any reported fire.
- Most reported fires were quickly extinguished by the crew (90% within 5 minutes). Only three reported fires took longer than 5 minutes to extinguish. Ninety-three percent of all reported fires were contained within the room of origin.
- Additional mishap data provided by Commandant (G-KSE-4) shows that the majority of high dollar loss fires originate in Engine Rooms.
- Forty-two percent of the fires occurred in port, 29% underway, 23% during a Yard period, and 6% unknown. Note that the period of time a vessel was undergoing FRAM, SLEP, or MMA was excluded.

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3. BASELINE FIRE SAFETY ANALYSIS

This section of the report will address the baseline fire safety analysis results organized as follows:

- SAFE Input Data. The sources for the factual and subjective input data needed to run SAFE are documented in this section.
- Baseline Fire Safety Analysis. The SFSEM/SAFE is used to perform the fire safety analysis of CGC DEPENDABLE based on the baseline data set. The baseline data set was populated with data determined from the ship visit, ship's drawings, compartment check-off lists, the cutter's Damage Control Book, and the cutter's Machinery Space Firefighting Doctrine.

3.1 SAFE INPUT DATA

The baseline analysis is founded on information collected and observed during the ship visit. There are two general types of input data required to run SAFE, factual and subjective. Factual data includes physical characteristics of the cutter, design information, and operational information such as:

- Type, location, and condition of bulkhead and deck materials
- Compartment deck area and height
- Type, location, and quantity of automated and manual fire protection equipment
- Type, location, and quantity of smoke, flame, and heat detectors
- Size and orientation of ventilation duct openings (exhaust and supply) and other ventilation openings
- Estimates of cellulosics, plastics, and flammable liquid fuel loads

Subjective data is more esoteric in nature and is established based on engineering judgment, default values, and comparisons to similar parameters on other ships. This data includes:

- Probabilities of flame termination
- Fire safety objectives
- Percent time monitored for each compartment
- Applicable fire growth models

The following sections provide additional information concerning input data collected or determined for the DEPENDABLE baseline fire safety analysis categorized into factual and subjective input data.

3.1.1 FACTUAL INPUT DATA

Data or information relative to the DEPENDABLE's physical characteristics, design, and operational configuration is considered to be factual data. Factual data is observed during the ship visit, determined from drawings and official documentation, or it is based on default values, rules of thumb, and certain assumptions. Factual data also includes estimated data. For example, it would be possible to exactly determine a compartment's fuel load by weighing each combustible. Since this is impractical, fuel loads are estimated based on engineering judgment and experience gained through numerous ship visits. The following sections describe input data relative to the ship's physical characteristics. Subjective input data, which is based on engineering judgment, is then discussed.

3.1.1.1 Ship's Geometry

The ship's drawings were converted into a three-dimensional rendition using AutoCAD, Release 12. Each compartment in the cutter was assigned a Compartment Use Indicator (CUI). Most of the default values established in SAFE are based on CUIs. Since some of the input data for the DEPENDABLE relies on default values, CUI assignments are particularly important. Type and location of bulkhead and deck materials are based on observations made during the ship visit and are documented in Appendix B, Table B.2. Compartment height and deck area are determined from the AutoCAD drawings and shown in Appendix B, Table B.1.1.

3.1.1.2 Automated and Manual Fire Protection Systems

The following descriptions of fire protection systems installed in DEPENDABLE were obtained from information collected during the ship visit, the cutter's Damage Control Book and Machinery Space Firefighting Doctrine:

- The firemain system is supplied by two electric fire pumps rated at 250 gpm each; one is located in the Engine Room (4-108-0-E) and the other in the Auxiliary Machinery Space (4-156-0-E). The firemain and fire stations are designed such that any location in the DEPENDABLE can be reached from at least two fire stations with a single 50-foot length of fire hose. The 3-inch firemain supplies salt water at 125 psi to firemain stations (hoselines), the AFFF firefighting system, the washdown system, and the magazine sprinkling system.
- Three P-250 portable fire pumps are available for firefighting and dewatering operations.
- A fixed CO_2 total flooding system is installed in the Flammable Liquids Storeroom.
- An aqueous potassium carbonate firefighting system is installed to extinguish grease fires in the Galley.
- Three AFFF foam stations are installed for fighting class B flammable liquid fires. Two of the stations are located at frame 66 on the port and starboard sides of the 01 weather deck for the purpose of combating fires on the flight deck. The third station is located in Passageway (2-156-01-L). Each station is equipped with an in-line foam proportioner, a foam liquid pickup tube, a 50-foot length of fire hose with varinozzle, and a 5-gallon container of foam liquid concentrate.
- An AFFF system consisting of a 100-gallon AFFF concentrate tank, pump, valves, and proportioner in Passageway (2-156-01-L) provides 6% AFFF to the following locations:

  a. Flight Deck Hose Stations located at frame 87 on the port side and frame 95 on the starboard side of the 01 Deck.

  b. Auxiliary Machinery Space (3-96-0-E)

  c. Auxiliary Machinery Space (4-156-0-E)

d. Engine Room Bilge and the AFFF Hose Reel in the Engine Room (4-108-0-E)

e. Steering Gear Room (4-188-0-E)

- The following magazines are protected by a seawater sprinkling system:

  a. Handling Room Passage (4-52-01-L)

  b. Small Arms Magazine (4-52-1-M)

  c. 25MM Magazine (4-62-1-M)

  d. 50MM Magazine (4-62-2-M)

  Saltwater sprinklers are installed to thoroughly wash down all weather decks and the exterior portions of the superstructure. This system is primarily designed to eliminate chemicals or radioactive contamination and is not intended for firefighting purposes.

- Portable CO_2 and PKP fire extinguishers are installed throughout the cutter.

The above list indicates that this cutter is well equipped with adequate quantities and appropriate types of automated and manual fire extinguishment equipment in order to respond to fire emergencies on this vessel. The location, type, and quantity of installed and portable fire protection equipment in DEPENDABLE is documented in Table B.5, Appendix B.

3.1.1.3 Fire Detection System

Based on observations and discussions with the crew, it appears that the original detection system prior to the Paragon project was unreliable and maintaining the system in a high state of readiness may have been given low priority. The input values for the percent time monitored for each compartment are based on the estimated time a compartment is monitored by persons in the crew or by an automatic detector. The methodology for assigning percent time monitored values is contained in Appendix E. The percent time monitored values for compartments in DEPENDABLE protected by automatic detectors reflects the fact that the original detection system was unreliable and not fully addressable. Crew notification of the fire is one of several factors considered in the calculation of the probabilities of automated and manual flame termination. The presence of automatic detectors increases the probability that the crew will be notified of a fire while it is still small. Table B.4, Appendix B, lists the location, quantity, and type of detectors installed in each compartment; in addition, the percent time monitored established for each compartment is shown as well as the estimated minutes to detection. This estimate is actually a calculated output from SAFE as described in Chapter V, Sections H.1 and H.2, of the SAFE User Manual [2].

The location, type, and quantity of installed fire detectors were observed during the ship visit. The type and quantity of all installed fire and smoke detectors are shown in Appendix B, Table B.4, including the calculated time to detection.

3.1.1.4 Ventilation

The size and orientation of both ventilation duct and other openings in each compartment were observed during the ship visit. The ventilation input data including area and average height of all ventilation openings in each compartment for the baseline analysis of the DEPENDABLE are documented in Appendix B, Table B.1.2.

3.1.1.5 Fuel Loads

Estimates of cellulosics, plastics, and flammable liquid fuel loads, documented in Appendix B, Table B.7, are based on fuel loads observed in each compartment during the ship visit.

3.1.2 SUBJECTIVE INPUT DATA

The SAFE analysis of USCGCs requires input data that is either an estimate of relative effectiveness or a qualitative assessment, both of which rely on engineering judgment. Engineering judgment expresses an experienced and knowledgeable person's degree of belief. The SFSEM is a probabilistic-based fire risk analysis methodology. Engineering judgment is therefore appropriate for determining the following:

- Probabilities of Flame Termination. There are three ways that flame movement can be terminated:
  - ➢ The fire can extinguish itself due to a lack of fuel, lack of oxygen, lack of heat to pyrolize the fuel, or a break in the chain reaction necessary for a fire to continue to burn. This is referred to as passive extinguishment because it occurs without automated or manual intervention.
  - ➢ The fire can be extinguished by application of a fire extinguishing agent from an automated fire protection system. This is referred to as automated extinguishment.
  - ➢ The fire can be extinguished by the manual application of a fire extinguishing agent. This is referred to as manual extinguishment.

  A probability for each of the above three methods of fire termination, given the fact that established burning has occurred in the compartment, is assigned for each compartment in the cutter. In addition, the probability that flame termination will occur, given the fact that fire enters a compartment as a result of a thermal or massive failure of a barrier, is assigned for each compartment in the cutter. Therefore a total of nine probabilities of flame termination are determined for each compartment in the cutter as described in Section 3.1.2.1 of this report.
- Fire Safety Objectives. A detailed explanation of the methodology for establishing FSOs is provided in Section 3.1.2.2 of this report.
- Percent Time Monitored. A detailed explanation of the methodology for estimating the percent of time each compartment is monitored is provided in Section 3.1.2.3 of this report.
- Fire Growth Models. A detailed explanation of the methodology for assigning fire growth models to each compartment is provided in Section 3.1.2.4 of this report.

3.1.2.1 Probabilities of Flame Termination

Probabilities of flame termination are documented in Appendix B, Tables B.6.1, B.6.2, and B.6.3, for in-port and at-sea scenarios. SAFE default values were used extensively, especially for the probabilities of flame termination in compartments entered as a result of a thermal (T-bar) or massive (D-bar) failure of a barrier. Probabilities of passive, automated, and manual means of flame termination for each compartment given EB in that compartment may be determined in accordance with the methodology documented in Appendix E of the final report of the Fire Safety Analysis of the 180' WLB Seagoing Buoy Tender [5]. This methodology was modified for use in this project to account for the changes implemented in DEPENDABLE as a result of the Paragon project. The revised methodology is documented in Appendix E of this report.

The probabilities of flame termination were calculated using network diagrams as described in Appendix F of the final report of the Fire Safety Analysis of the 180' WLB Seagoing Buoy Tender. [5] Probabilities were assigned to each of the subfactors at the lowest level of detail for I, A, and M values as described in Appendix G of the report and in the Theoretical Basis of the SFSEM. [5, 1] For example, the following illustrates how the "A-Value" of 0.24 was determined as the probability of flame termination by automated means in the Flammable Liquids Storeroom that is protected by an installed CO_2 flooding system:

Probability of Notification (An)

An = dan * nan* san = 0.70 * 0.70 * 0.95 = 0.47 where:

dan = probability of detection

nan = notification of Pilot House

san = sound the alarm

Probability of Preparation (Ap)

Ap = fap * vap * pap = 1.00 * 0.80 * 0.90 = 0.72 where:

fap = securing the fuel supply to internal combustion engines in the space

vap = securing the ventilation fans in the space

pap = securing the electrical power in the space

Probability of Agent Application (Aa)

Aa = saa * aaa * daa = 0.95 * 1.00 * 1.00 = 0.95 where

saa = automated system is properly aligned for operation

aaa = agent discharges from the nozzle(s)

daa = agent discharges on the fire

Probability of Fire Extinguishment (Ae)

Ae = qae * cae * bae = 1.00 * 0.90 * 0.85 = 0.77 where

qae = quantity of agent is adequate

cae = concentration of agent is adequate

bae = blackout occurs

Probability of Flame Termination by Automated Means (A)

A = An * Ap * Aa * Ae = 0.47 * 0.72 * 0.95 * 0.77 = 0.24

3.1.2.2 Fire Safety Objectives

In order to analyze the performance of a ship as a fire safety system**,** there must be acceptable performance standards or criteria established by cognizant authorities. These criteria are referred to as Fire Safety Objectives (FSOs). The development of FSOs should take into consideration life safety, property protection, and mission impairment. Ideally, FSOs are established by owners or cognizant authorities who have been delegated responsibility for the management of ship operations and who are knowledgeable of fire protection engineering principles. In the Coast Guard, cognizant authorities are the appropriate program and support managers in Coast Guard Headquarters. In the absence of such input, FSOs were established by the engineer/analyst using the process described in this section. As the purpose of this project was to establish the relative impact of changes implemented by the Paragon Implementation Team on shipboard fire safety levels, the actual FSOs are similarly relative.

FSOs are designed to establish the performance standard for a fire safety system taking into account all aspects of fire including flame movement, smoke movement, people movement (egress for the occupants), and the ability of the structure to withstand the fire's assault. In the SFSEM, smoke movement, people movement, and structural analysis modules are not yet fully developed; therefore the FSOs are presently established considering flame movement only.

FSOs were established for the DEPENDABLE for each compartment utilizing the traditional approach used over the past 10 years in the fire safety analysis of 16 classes of Coast Guard cutters. A number of limitations and drawbacks have been identified with the traditional approach, and there has been some discussion concerning the practicality and validity of establishing FSOs on a compartment basis. [6, 7] Even with these minor concerns, the traditional approach has merit and is considered a valid approach. The following paragraphs describe the traditional approach in more detail.

FSOs are established for each compartment in the cutter that may be analyzed by SAFE. Currently, magazines, flammable liquid tanks, and helicopter hangars are not analyzed due to the inability of SAFE to deal with explosion hazards. All other compartments are rated for both Magnitude of Acceptable Loss (MAL) and Frequency of Acceptable Loss (FAL). The MAL is established by assigning a rating to each of the following four factors for each compartment and then weighting these factors to determine an overall rating for the compartment:

- Life Safety (LS)
- Property Protection (PP)
- Primary Mission (PM)
- Secondary Mission (SM)

The weighting factors are different for each module in the SFSEM. For example, in the flame movement module, damage from flames affects the primary mission of the ship more than it causes life safety concerns. Whereas considering the effects of smoke, life safety will be the primary concern compared to property damage. Thus the weighting factors for the four factors are adjusted for each module in the SFSEM. The weighting factors used to assign a MAL rating to each compartment in the DEPENDABLE considering flame movement only are shown in the following expression:

$$\mathbf{MAL = 0.1{*}LS + 0.3{*}PP + 0.4{*}PM + 0.2{*}SM}$$

The MAL rating for each factor (LS, PP, PM, & SM) is permitted to be one of the following four integer values:

Established Burning (EB) is not acceptable……………………. 1

EB is acceptable but Full Room Involvement (FRI) is not…….. 2

FRI is acceptable but Compartment Burnout (CBO) is not……. 3

CBO is acceptable……………………………………………… 4

A MAL rating is assigned to each factor for each compartment, then the overall MAL rating is calculated according to the algebraic expression shown above and the truncated MAL rating is assigned to the compartment. For example, if the result of the calculation is 3.37, a MAL of 3 is assigned.

The ratings are assigned for each factor using engineering judgment and considering the effect flame movement has on each factor. Compartments whose total loss (CBO) would not significantly affect the ship's primary or secondary mission are typically assigned a rating of 4 for factors PM and SM. For example, if totally lost, most sanitary spaces, gear lockers, passageways, voids, water tanks, ladders, cofferdams, and certain storerooms would not prevent the ship from performing its primary or secondary mission. Note that a compartment may contain a significant fuel load and contribute materially to the spread of a fire, but if its loss does not significantly affect the ship's mission, it receives a rating of 4. At the other extreme, flammable materials storage lockers, paint lockers, and other compartments containing extremely flammable materials representing a significant fire hazard are normally assigned a rating of 1 for the factors PM and SM.

The balance of the compartments are normally assigned a rating of 2 or 3 for the factors PM and SM. In general, if the compartment contains equipment vital to the ship's primary or secondary mission, and if its loss would likely result in the ship is aborting its patrol and returning to homeport for repairs, it would be assigned a 2. On the other hand, if the compartment's loss would degrade but not prevent the ship's ability to perform its mission, it would receive a 3 rating. Examples of compartments typically rated 2 for the factors PM or SM are the Engine Room, Bridge, and Galley. Berthing Areas, Ship's Offices, and Labs/Workshops are typically assigned a 3 rating for the factors PM and SM. Note: If a compartment would normally be assigned a MAL of 4 for PM and SM factors, but it contains wiring that serves vital systems or equipment in other spaces, the MAL ratings for the PM and SM factors are assigned to match the rating assigned to those spaces that contain the vital systems or equipment.

The cost to replace a compartment's contents (machinery and outfit) is the primary consideration for assigning a rating to the property protection (PP) factor. Obviously, Engineering Spaces such as the Engine Room, Emergency Generator Room, and Auxiliary Machinery Rooms contain very expensive machinery not only from an acquisition point of view but also in respect to the costs for the labor to install and align the equipment. Thus these spaces are typically assigned a rating of 2 for the PP factor. A rating of 1 is assigned to spaces such as paint lockers and flammable materials storage lockers for the property protection factor due to the additional property damage that would undoubtedly occur in other adjacent spaces. A rating of 4 is assigned for the PP factor to those spaces whose total loss would be considered minimal (compared with other spaces). Finally, a rating of 3 is assigned for the PP factor to those compartments whose cost is not minimal but is considered far less than major engineering spaces. Examples of spaces assigned a 3 rating for the PP factor include the Galley, the Scullery, and spaces with some minor machinery such as sewage machinery spaces and potable water equipment rooms.

Ratings for the life safety (LS) factor take into account the likelihood that personnel will be injured by the fire (not by the smoke or toxic gases). This probability is affected by the likelihood that the space will be occupied, the accessibility of the space, the quantity of personnel likely to be in the space, and the likelihood that the occupants will be sleeping. Thus spaces such as the Paint Locker, where personnel would be in danger even if EB occurs, are assigned a rating of 1 for the LS factor. Spaces in which EB can occur, but personnel are not likely to be in serious danger unless FRI occurs, receive a rating of 2 for the LS factor. If FRI can be tolerated but the entire compartment would have to be lost before personnel are in danger of being injured, a rating of 3 would be appropriate for the LS factor. Finally, if a compartment can be totally lost and still not endanger personnel, a rating of 4 can be assigned to the LS factor. After a rating has been assigned to all four factors, the overall MAL rating for the compartment is calculated. This value is then used in the calculation for the Frequency of Acceptable Loss (FAL) as described in the next paragraph.

The FAL is related to the MAL. For example, it may be considered acceptable to lose a compartment with a MAL = 4 once a year, but compartments with a MAL = 1 may be lost only once in a ship's lifetime (30 years). Based on MAL and FAL ratings established by engineering judgment for similar compartments in several classes of cutters, a correlation between MAL and FAL was determined by fitting a curve to the data points. The following algebraic relationship expresses this correlation and is used to establish the FAL based on the nontruncated MAL rating for each compartment:

$$\mathbf{FAL = 32.25 - (1.766*MAL) - (0.214*MAL^2) - (0.222*MAL^3)}$$

The FSOs established for the DEPENDABLE using the traditional approach described above are tabulated in Appendix B, Table B.3.

3.1.2.3 Percent Time Monitored

The time to detect a fire is a function of the percent of time a compartment is monitored. There are two possible ways a compartment can be monitored: by the ship's crew or by an installed smoke, heat, or flame detector. In compartments monitored by installed detectors that are wired to a fully addressable central alarm panel, 95% is normally assigned (99% in the event of multiple detectors in a compartment) as the percent of time the compartment is monitored both in port and at sea. This value reflects the reliability expected with this type of detection system. As discussed earlier, since the detection system in DEPENDABLE prior to the Paragon project is not fully addressable or reliable, the percent time monitored in compartments with installed detectors was significantly reduced as shown in Appendix B, Table B.4. In other compartments not protected by detectors engineering judgment was utilized to estimate the percentage of time per 24-hour day that a particular compartment is expected to be monitored (visited) by a crew member.

Percent time monitored values are used as the probability of detection subfactor in the assignment of flame termination by automated means (A-values) and by manual means (M-values). To ensure that these values are assigned in a consistent manner, a methodology for assigning M-values was developed and documented in the final report of the Fire Safety Analysis of the 180' WLB Seagoing Buoy Tender. [5] This methodology was modified to account for the changes implemented in the Paragon project in DEPENDABLE and documented in Appendix E of this report.

3.1.2.4 Fire Growth Models

There are 16 fire growth models in SAFE that describe the nature and distribution of fuel packages. The particular model that is selected predetermines two extremely important fire growth parameters: alpha and Qmax. Alpha is the fire growth coefficient in the heat release rate formula in the pre-FRI fire growth regime. Qmax describes the maximum heat release rate that is permitted regardless of the fuel load. These parameters in the fire growth models were based on empirical data collected in full-scale tests. These tests were conducted in warehouses, basements, and other nonshipboard scenarios. Consequently, many of the available fire growth models are a poor match to shipboard conditions; however, their application in SAFE is considered to give conservative results. Fire growth models were assigned based on observations during the ship visit of the fuel loads in each compartment. Fire growth models selected for the DEPENDABLE are documented in Appendix B, Table B.8.

3.2 BASELINE FIRE SAFETY ANALYSIS RESULTS

3.2.1 FRI TIMES AND POST-FRI HEAT RELEASE RATES

The Post-FRI heat release rates (Q) and FRI times are calculated in SAFE. These fire parameters are tabulated for each compartment in Appendix B, Table B.8. The algorithms for these calculations are described in the Theoretical Basis of the SFSEM. [1]

FRI time is a critically important fire parameter because it determines the length of time between EB and the development of sufficiently high compartment temperatures that full room involvement conditions are expected. When FRI is achieved, conditions in the compartment are assumed to be incapable of supporting life, and the heat energy of the burning fuel is assumed to begin impacting the barriers. Therefore, if FRI time is infinite (or greater than 60 minutes for practical purposes) the fire will be limited to the compartment. On the other hand, if FRI time is very short (for example, 2 or 3 minutes), there may be little chance that the fire party can respond quickly enough to extinguish the fire in the compartment unless there is a very small fuel load. If the fuel load is small, the available fuel may be consumed quickly and the fire may be easily extinguished by the fire party. The ability to achieve FRI is largely dependent on ventilation. Stoichiometric burning conditions are assumed to exist in each compartment. In an actual ship, many compartments may be rendered relatively airtight, thus this is a conservative assumption. A review of the calculated FRI times tabulated in Appendix B, Table B.8, shows expected results for all compartments.

3.2.2 ANALYZE BASELINE RESULTS

The following summarizes some of the basic assumptions made in SAFE and by the analyst that affect the results of the fire safety analysis:

- FRI times are based on a rise of ambient temperatures in the compartment of 500°C.
- Rate of heat release in the pre-FRI fire growth regime is based on an "alpha-T-squared" fire growth curve.
- Rate of heat release in the post-FRI fire growth regime is calculated according to the following formula: $1500*A*H^{0.5}$ (stoichiometric combustion conditions).
- The Ingberg conversion is used for the determination of heat energy impact on the barriers. Moreover this heat energy is assumed to impact the barriers only after FRI is achieved.
- Fire paths are assumed to be *independent* in the individual target option. Since actual fire paths are *dependent,* the results predict that target compartments are not as safe as they actually are.
- In a fire, ventilation fans are usually secured. Significantly less air can flow through the ductwork than the natural vent opening assumed in the calculations.
- An unimpaired, fully trained 75-person crew is assumed to be on board underway. A fully manned and trained in port duty section is on board in port with all persons in the repair party fully qualified for their roles.

The net effect of these assumptions on the results is considered conservative. In other words it is believed that the fire safety of this ship is actually better (safer) than the results indicate.

3.2.2.1 Individual Target Option Results

The individual target option was specified as the output option for running the probabilistic model in the fire safety analyses of previous cutters as well as the DEPENDABLE. This option permits a rapid comparison of each compartment as a target compartment compared with preestablished fire safety objectives for fires that may originate in any compartment. In other words, it provides a means to identify "victims" of fires that may start in any compartment (including the target) and ultimately involve the target compartment. Results of the baseline fire safety analysis with the individual target option run on the baseline data set are documented in Appendix C, Individual Target Option - Summary Level Reports.

Excerpts from the individual target option results are shown in Tables 3.1, 3.2, and 3.3 and list all compartments with RLFs greater than or equal to 0.03 and a MAL of 1, 2, or 3 in scenario 1 (XRAY, In Port, I, A, & M in effect). These three tables summarize the most interesting results of the baseline analysis. The RLFs shown in Table 3.1 for the two in-port scenarios (XRAY and YOKE) are very similar. This indicates that there are relatively few doors, scuttles, and hatches labeled YOKE. A review of the access classifications in Appendix B, Table B.2, reveals that there are only seven watertight doors and four hatches classified YOKE. The most significant difference between the XRAY and YOKE in-port scenarios is the Engine Room. The YOKE door in the Engine Room leading to Passageway, 2-140-0-L, accounts for why the XRAY scenario is significantly less safe.

The small differences in the two YOKE scenarios, in port and at sea (scenarios 2 and 3), shown in Table 3.1 are primarily attributed to the difference in the percent (time) monitored for each compartment in port and at sea as documented in Appendix B, Table B.4. In general, it is more likely that a crew member will discover a fire earlier at sea than in port due to the higher manning levels at sea. Therefore, lower RLFs (safer ship) are expected for at-sea scenarios than for in-port scenarios. Another reason that accounts in part for the small difference between the two YOKE scenarios shown in Table 3.1 is the fact that the relative contribution of automated (A) and manual (M) suppression is small; therefore the results are largely attributable to passive (I) protection only. Since there is virtually no difference in passive protection at sea and in port, very little difference is expected in results between the two YOKE scenarios.

A review of the baseline fire safety analysis results show that with passive (I), automated (A), and manual (M) fire protection in effect, all compartments in the pre-Paragon DEPENDABLE exceed FSOs, in port and at sea. This means that no improvements are necessarily required to bring the pre-Paragon DEPENDABLE up to minimally acceptable fire safety levels.

Table 3.2 compares varying levels of fire protection for the in-port, XRAY scenario. As expected, the RLFs increase with decreasing levels of fire protection. The results also show that the rank ordering of compartments from most dangerous (highest RLF) to safest (lowest RLF) is approximately the same among the four scenarios. As shown in Table 3.2, all compartments exceed FSOs with all combinations of fire protection in effect (I only; I & A; I & M; and I, A, & M). Therefore passive fire protection alone (I only) is adequate to meet FSOs. Automated and manual fire extinguishment increase the margin of safety. A comparison of results between I only and I & M shows the minimal contribution of manual firefighting efforts to the overall fire safety of the ship. Similarly, there is no significant improvement between I only and I & A in RLFs for most target compartments. This result is attributed to the fact that only six compartments (other than magazines, which are not analyzed) are protected by an automated system. The very slight increase between I & A and I, A, &M results is due to the slight improvement added by manual firefighting efforts. In summary, the pre-Paragon DEPENDABLE exceeds fire safety objectives in port in all compartments, with and without the contribution of either automated or manual firefighting.

Table 3.3 compares varying levels of fire protection for the at-sea YOKE scenario. As expected, the RLFs increase with decreasing levels of fire protection. The results also show that the rank ordering of compartments from most dangerous (highest RLF) to safest (lowest RLF) is approximately the same among the four scenarios. As shown in Table 3.3, all compartments exceed FSOs with all combinations of fire protection in effect (I only; I & A; I & M; and I, A, & M). Therefore passive fire protection alone (I only) is adequate to meet FSOs. Automated and manual fire extinguishment increases the margin of safety. A comparison of results between I only and I & M shows the minimal contribution of manual firefighting efforts to the overall fire safety of the ship. Similarly, there is no significant improvement between I only and I & A in RLFs for most target compartments. This result is attributed to the fact that only six compartments (other than magazines, which are not analyzed) are protected by an automated system. The very slight increase between I & A and I, A, &M results is due to the slight improvement added by manual firefighting efforts. In summary, the pre-Paragon DEPENDABLE exceeds fire safety objectives at sea in all compartments, with and without the contribution of either automated or manual firefighting.

Table 3.1
Relative Loss Factors, Scenarios 1, 2, 3

Plan ID	Compartment Name	CUI	MAL	FAL	Run 10-37	Run 10-41	Run 6-17
					Scenario 1	Scenario 2	Scenario 3
					Xray, In Port	Yoke, In Port	Yoke, At Sea
4-108-0-E	Engine Room	EM	2	26	0.338	0.019	0.019
01-99-0-Q	Uptake & Fan Room	TU	2	23	0.105	0.105	0.102
03-62-0-C	Pilot House	C	2	26	0.104	0.104	0.099
02-56-1-C	Radio Room	C	2	26	0.062	0.062	0.060
02-90-0-Q	Plenum Room	QF	3	18	0.044	0.044	0.042
02-56-2-C	CIC Room	C	2	26	0.042	0.042	0.041
1-108-0-Q	Uptake	TU	2	23	0.041	0.041	0.040
01-92-0-Q	Helo Service Room	QA	2	22	0.040	0.040	0.039
1-114-2-Q	Scullery	QG	2	20	0.038	0.038	0.038
2-172-1-A	Hawser & Rescue Equipment	AS	2	22	0.038	0.023	0.022
1-20-0-Q	Laundry	QL	3	19	0.036	0.000	0.000
1-93-0-L	CPO Mess	LL	2	24	0.034	0.034	0.033
1-121-0-L	Crews Mess	LL	2	24	0.033	0.033	0.032
4-188-0-E	Steering Gear Room	QA	2	26	0.032	0.009	0.008

Compartments listed have
MAL of 1-3 and RLF>.03 in Scenario 1

All Scenarios include I, A, and M

Table 3.2
Relative Loss Factors, Scenarios 1, 4, 7, 10

Plan ID	Compartment Name	CUI	MAL	FAL	Run 10-37	Run 10-38	Run 10-39	Run 10-40
					Scenario 1	Scenario 4	Scenario 7	Scenario 10
					I, A, & M	I & A	I & M	I Only
4-108-0-E	Engine Room	EM	2	26	0.338	0.366	0.398	0.432
01-99-0-Q	Uptake & Fan Room	TU	2	23	0.105	0.124	0.108	0.128
03-62-0-C	Pilot House	C	2	26	0.104	0.199	0.104	0.199
02-56-1-C	Radio Room	C	2	26	0.062	0.086	0.062	0.086
02-90-0-Q	Plenum Room	QF	3	18	0.044	0.050	0.045	0.052
02-56-2-C	CIC Room	C	2	26	0.042	0.062	0.042	0.062
1-108-0-Q	Uptake	TU	2	23	0.041	0.045	0.042	0.048
01-92-0-Q	Helo Service Room	QA	2	22	0.040	0.044	0.040	0.045
1-114-2-Q	Scullery	QG	2	20	0.038	0.045	0.041	0.048
2-172-1-A	Hawser & Rescue Equipment	AS	2	22	0.038	0.047	0.040	0.051
1-20-0-Q	Laundry	QL	3	19	0.036	0.040	0.036	0.040
1-93-0-L	CPO Mess	LL	2	24	0.034	0.048	0.036	0.051
1-121-0-L	Crews Mess	LL	2	24	0.033	0.048	0.036	0.053
4-188-0-E	Steering Gear Room	QA	2	26	0.032	0.037	0.037	0.043

Compartments listed have
MAL of 1-3 and RLF>.03 in Scenario 1

All Scenarios are XRAY In Port

Table 3.3
Relative Loss Factors, Scenarios 3, 6, 9, 12

Plan ID	Compartment Name	CUI	MAL	FAL	Run 6-17	Run 6-18	Run 6-19	Run 6-20
					Scenario 3	Scenario 6	Scenario 9	Scenario 12
					I, A, & M	I & A	I & M	I Only
4-108-0-E	Engine Room	EM	2	26	0.019	0.023	0.023	0.029
01-99-0-Q	Uptake & Fan Room	TU	2	23	0.102	0.124	0.104	0.128
03-62-0-C	Pilot House	C	2	26	0.099	0.193	0.099	0.193
02-56-1-C	Radio Room	C	2	26	0.060	0.084	0.060	0.084
02-90-0-Q	Plenum Room	QF	3	18	0.042	0.050	0.043	0.052
02-56-2-C	CIC Room	C	2	26	0.041	0.058	0.041	0.058
1-108-0-Q	Uptake	TU	2	23	0.040	0.045	0.042	0.048
01-92-0-Q	Helo Service Room	QA	2	22	0.039	0.044	0.040	0.045
1-114-2-Q	Scullery	QG	2	20	0.038	0.045	0.041	0.048
2-172-1-A	Hawser & Rescue Equipment	AS	2	22	0.022	0.029	0.023	0.030
1-20-0-Q	Laundry	QL	3	19	0.000	0.000	0.000	0.000
1-93-0-L	CPO Mess	LL	2	24	0.033	0.048	0.035	0.051
1-121-0-L	Crews Mess	LL	2	24	0.032	0.048	0.036	0.053
4-188-0-E	Steering Gear Room	QA	2	26	0.008	0.011	0.010	0.014

Compartments listed have
MAL of 1-3 and RLF>.03 in Scenario 1

All Scenarios are YOKE At Sea

4. ANALYSIS OF POST-PARAGON CONDITIONS

As noted in Section 3 of this report, all compartments in the DEPENDABLE exceed their fire safety objectives. Therefore no changes to the existing fire safety systems are required to bring the ship up to minimally acceptable fire safety standards. However, as a consequence of the Paragon Project, a significant reduction in crew size was implemented. The in-port duty section size was significantly reduced to five persons while the cutter is in homeport. When the DEPENDABLE is in a port other than its homeport, there is no change in the in-port duty section size. The original fire detection system was changed to a more reliable and fully addressable system. A reduction in crew size and an improved fire detection system have offsetting effects on fire safety. The Coast Guard initiated this study to evaluate the impact of the Paragon project changes on the ship's fire safety. It is important to recognize that since the Paragon project changes impact only A and M values, the DEPENDABLE will still meet the FSOs as the I values (passive fire protection) remain unchanged.

To accomplish the objectives of this study, a fire safety analysis using the SFSEM/SAFE was performed on the DEPENDABLE under pre-Paragon and post-Paragon conditions, and the results were compared to quantify the net effect on fire safety of the changes implemented in the Paragon project. This section of the report is organized into three subsections:

- Changes Implemented in the Paragon Project. The changes that affect fire safety that were implemented in DEPENDABLE as a result of the Paragon Project are described in Section 4.1 of this report.
- Post-Paragon Fire Safety Analysis. The results of running SAFE and the individual target option on the Post-Paragon DEPENDABLE are discussed in Section 4.2 of this report
- Comparison of Pre-Paragon and Post-Paragon Results. The results of running SAFE on the Post-Paragon conditions are compared to the baseline (pre-Paragon) results and the net effect on fire safety is discussed in Section 4.3 of this report.

4.1 CHANGES IMPLEMENTED IN THE PARAGON PROJECT

The following changes associated with the Paragon project were implemented on DEPENDABLE:

- The existing fire detection system was changed to a fully addressable system. However, only compartments that initially contained detector heads are covered. The original system was divided into 16 zones, most of which included multiple compartments. Under this system, a detection alarm required an investigator to search the compartments comprising the zone to determine the exact location of the fire. This information would then be transmitted to the Bridge by messenger or by some internal communications system where an announcement of the fire location would be made. The new detection system is fully addressable; that is, the compartment where the detector is located is automatically and immediately displayed on the master alarm panel. The existing detector heads were changed to support the new addressable alarm panel, but the original wiring was reused. As stated previously, locations of detectors were not modified.
- Sixteen fixed surveillance cameras were installed in strategic locations throughout the vessel. TV monitors located throughout the ship constantly display the view from one of the cameras. The crew can control the sequence and length of display from each camera. In addition, a portable laptop computer that can be plugged into the system in multiple locations throughout

the ship, is used to control the system. The laptop computer can command a constant display from a selected camera during a fire incident.

- The fire detection and monitoring system was combined with other alarms including the bilge high water level alarm and the magazine high temperature alarm. The system is also integrated with the surveillance cameras, TV monitors mounted in strategic locations, and the general announcing system. The system is designed to automatically make an announcement of the compartment location of a fire as soon as it is detected. In addition, the nearest surveillance camera automatically locks in so that all TV monitors provide a continuous view of the scene near the fire.
- A four- to five-person rapid response team (RRT), modeled after a concept developed by the Navy, is used to immediately respond to all fires in port and at sea. The RRT does not take the time to dress out in firefighting ensembles. They immediately respond to the scene of the fire with portable extinguishers. If they are unsuccessful in extinguishing the fire, they back out of the space and contain the fire by closing all doors and hatches in the vicinity of the fire. The repair party will then relieve the RRT of firefighting duties.
- At sea and in port away from homeport, one repair party is fully manned (opposed to two in other 210' WMEC cutters) and responds to all fires after firefighters don firefighting ensembles. The repair party responds to the scene after breaking out appropriate firefighting equipment such as hoses, and AFFF.
- In homeport, the normal duty section is reduced to five persons. Because the normal duty section is reduced, DEPENDABLE will augment the firefighting capabilities with assistance from city fire department personnel as well as potential assistance from other cutters in port. It is important to recognize that the in-port duty section is reduced only under “cold iron” conditions. “Cold iron” conditions preclude the operation of the main engines or the ship’s service generators.
- Most crew members have been given personal wireless portable communication devices. These devices are capable of tying into the general announcing system. Presently, these devices cannot be used with an oxygen breathing apparatus. There are plans to alter the OBA helmets to permit hands-free use of the portable phone.

Some of the features of the new fire detection and monitoring system have not been implemented due to technical difficulties encountered during installation. For example, currently the laptop computer will not interface with the detection system; therefore the surveillance cameras can only be controlled or locked on to a constant display from the IC Gyro Room. This analysis is based on the features of the new system that were operable during the ship visit in October 1998. Features of the new system that have not been accounted for should only improve fire safety on DEPENDABLE.

4.2 POST-PARAGON FIRE SAFETY ANALYSIS

The changes that were implemented in DEPENDABLE as a result of the Paragon project do not affect the probabilities of passive flame termination. No changes were made to installed or fixed fire protection equipment with the exception of the fire detection system. Fire safety objectives, fuel loads, ventilation values, and all other important parameters that affect fire safety were not affected by the Paragon project. Therefore, all the changes described above affect the assignment of probabilities of automated and manual flame termination. A-values and M-values were assigned in accordance with the revised methodology described in Appendix E of this report. The inputs to the post-Paragon fire safety analysis in the form of detailed A-value and M-value spreadsheets and a complete set of outputs in the form of individual target summary level reports are included in Appendix D of this report.

Excerpts from the individual target option results are shown in Tables 4.1, 4.2, and 4.3 and list all compartments with RLFs greater than or equal to 0.03 and a MAL of 1, 2, or 3 in scenario 1 (XRAY, In Port, I, A, & M in effect). These three tables summarize the most interesting results of the post-Paragon analysis.

Tables 4.1, 4.2, and 4.3 compare varying levels of fire protection for the following scenarios:

- Table 4.1: At sea, YOKE.
- Table 4.2: In port, in homeport, XRAY
- Table 4.3: In port, away from homeport, XRAY

As expected, the RLFs increase with decreasing levels of fire protection. The results also show that the rank ordering of compartments from most dangerous (highest RLF) to safest (lowest RLF) is approximately the same among the four scenarios. As shown in Tables 4.1, 4.2, and 4.3, all compartments exceed FSOs with all combinations of fire protection in effect (I only; I & A; I & M; and I, A, & M). Therefore, passive fire protection alone (I only) is adequate to meet FSOs. Automated and manual fire extinguishment increase the margin of safety. A comparison of results between I only and I & M shows the minimal contribution of manual firefighting efforts to the overall fire safety of the ship. Similarly there is no significant improvement between I only and I & A in RLFs for most target compartments. This result is attributed to the fact that only six compartments (other than magazines, which are not analyzed) are protected by an automated system. The very slight increase between I & A and I, A, &M results is due to the slight improvement added by manual firefighting efforts. **In summary, the post-Paragon DEPENDABLE exceeds fire safety objectives at sea in all compartments, at sea and in port, with and without the contribution of either automated or manual firefighting**. This means that no improvements are necessarily required to bring the post-Paragon DEPENDABLE up to minimally acceptable fire safety levels.

Table 4.1
Relative Loss Factors, Scenarios 3, 6, 9, 12

Plan ID	Compartment Name	CUI	MAL	FAL	Run 14-63	Run 14-64	Run 14-65	Run 14-66
					Scenario 3	Scenario 6	Scenario 9	Scenario 12
					I, A, & M	I & A	I & M	I Only
4-108-0-E	Engine Room	EM	2	26	0.011	0.020	0.016	0.029
01-99-0-Q	Uptake & Fan Room	TU	2	23	0.081	0.121	0.084	0.128
03-62-0-C	Pilot House	C	2	26	0.073	0.193	0.073	0.193
02-56-1-C	Radio Room	C	2	26	0.046	0.084	0.046	0.084
02-90-0-Q	Plenum Room	QF	3	18	0.035	0.049	0.036	0.052
02-56-2-C	CIC Room	C	2	26	0.031	0.058	0.031	0.058
1-108-0-Q	Uptake	TU	2	23	0.032	0.043	0.034	0.048
01-92-0-Q	Helo Service Room	QA	2	22	0.030	0.044	0.031	0.045
1-114-2-Q	Scullery	QG	2	20	0.026	0.042	0.028	0.048
2-172-1-A	Hawser & Rescue Equipment	AS	2	22	0.013	0.029	0.013	0.030
1-20-0-Q	Laundry	QL	3	19	0.000	0.000	0.000	0.000
1-93-0-L	CPO Mess	LL	2	24	0.021	0.046	0.022	0.051
1-121-0-L	Crews Mess	LL	2	24	0.018	0.044	0.023	0.053
4-188-0-E	Steering Gear Room	QA	2	26	0.005	0.010	0.006	0.014

Compartments listed have
MAL of 1-3 and RLF>.03 in Scenario 1

All Scenarios are YOKE At Sea

Table 4.2
Relative Loss Factors, Scenarios 1, 4, 7, 10

Plan ID	Compartment Name	CUI	MAL	FAL	Run 15-67	Run 15-68	Run 15-69	Run 15-70
					Scenario 1	Scenario 4	Scenario 7	Scenario 10
					I, A, & M	I & A	I & M	I Only
4-108-0-E	Engine Room	EM	2	26	0.306	0.330	0.399	0.432
01-99-0-Q	Uptake & Fan Room	TU	2	23	0.094	0.121	0.097	0.128
03-62-0-C	Pilot House	C	2	26	0.107	0.199	0.107	0.199
02-56-1-C	Radio Room	C	2	26	0.059	0.086	0.059	0.086
02-90-0-Q	Plenum Room	QF	3	18	0.039	0.049	0.040	0.052
02-56-2-C	CIC Room	C	2	26	0.039	0.062	0.039	0.062
1-108-0-Q	Uptake	TU	2	23	0.034	0.043	0.036	0.048
01-92-0-Q	Helo Service Room	QA	2	22	0.035	0.044	0.036	0.045
1-114-2-Q	Scullery	QG	2	20	0.027	0.042	0.031	0.048
2-172-1-A	Hawser & Rescue Equipment	AS	2	22	0.027	0.044	0.031	0.051
1-20-0-Q	Laundry	QL	3	19	0.031	0.040	0.031	0.040
1-93-0-L	CPO Mess	LL	2	24	0.027	0.046	0.028	0.051
1-121-0-L	Crews Mess	LL	2	24	0.024	0.044	0.031	0.053
4-188-0-E	Steering Gear Room	QA	2	26	0.025	0.032	0.033	0.043

Compartments listed have
MAL of 1-3 and RLF>.03 in Scenario 1

All Scenarios are XRAY In Port

Table 4.3
Relative Loss Factors, Scenarios 1, 4, 7, 10

Plan ID	Compartment Name	CUI	MAL	FAL	Run 16-75	Run 16-76	Run 16-77	Run 16-78
					Scenario 1	Scenario 4	Scenario 7	Scenario 10
					I, A, & M	I & A	I & M	I Only
4-108-0-E	Engine Room	EM	2	26	0.272	0.330	0.355	0.432
01-99-0-Q	Uptake & Fan Room	TU	2	23	0.083	0.121	0.086	0.128
03-62-0-C	Pilot House	C	2	26	0.077	0.199	0.077	0.199
02-56-1-C	Radio Room	C	2	26	0.047	0.086	0.047	0.086
02-90-0-Q	Plenum Room	QF	3	18	0.036	0.049	0.037	0.052
02-56-2-C	CIC Room	C	2	26	0.031	0.062	0.031	0.062
1-108-0-Q	Uptake	TU	2	23	0.033	0.043	0.034	0.048
01-92-0-Q	Helo Service Room	QA	2	22	0.031	0.044	0.031	0.045
1-114-2-Q	Scullery	QG	2	20	0.026	0.042	0.028	0.048
2-172-1-A	Hawser & Rescue Equipment	AS	2	22	0.019	0.044	0.022	0.051
1-20-0-Q	Laundry	QL	3	19	0.025	0.040	0.025	0.040
1-93-0-L	CPO Mess	LL	2	24	0.022	0.046	0.023	0.051
1-121-0-L	Crews Mess	LL	2	24	0.018	0.044	0.024	0.053
4-188-0-E	Steering Gear Room	QA	2	26	0.022	0.032	0.029	0.043

Compartments listed have
MAL of 1-3 and RLF>.03 in Scenario 1

All Scenarios are XRAY In Port

4.3 COMPARISON OF BASELINE AND POST-PARAGON RESULTS

A comparison of the pre-Paragon fire safety analysis results with the post-Paragon results provides the net effect of all changes associated with the Paragon project that affect fire safety. The pre-Paragon results are discussed in Section 3.2.2.1 of this report and summarized in Tables 3.1, 3.2, and 3.3. The post-Paragon results are discussed in Section 4.2 and summarized in tables 4.1, 4.2, and 4.3. These tables summarize results from running SAFE with the individual target option that are included in Appendix D. The results of the in-port, YOKE SAFE runs are, as expected, safer than the XRAY scenarios. The SAFE runs for in-port, YOKE scenarios are included in Appendix D for the sake of completeness. Table 4.4 lists the SAFE runs and Tables that summarize these results.

Table 4.4: Comparable Pre- and Post-Paragon Results

Scenario	Pre-Paragon		Post-Paragon	
	Table in Text of Report	SAFE Run Numbers in Appendix D	Table in Text of Report	SAFE Run Numbers in Appendix D
In Port XRAY, Scenarios 1, 4, 7, & 10	Table 3.2	10-37 through 10-40	Table 4.2, & Table 4.3	15-67 through 15-70 16-75 through 16-78
In Port, YOKE, Scenarios 2, 5, 8, & 11		10-41 through 10-44		15-71 through 15-74 16-79 through 16-82
At Sea, YOKE, Scenarios 3, 6, 9, & 12	Table 3.3	6-17 through 6-20	Table 4.1	14-63 through 14-66

As expected, the results for I only scenarios are identical for pre- and post-Paragon conditions. Since A-values and M-values were changed, I&A, I & M, and I, A, & M results should differ.

The following describes expected changes in fire safety as a result of changes implemented in the Paragon project:

- The reduction in the homeport duty section size should cause fire safety to decrease because of a reduction in manual firefighting effectiveness caused by a delay in firefighters responding to the scene since they are coming from the local fire department or another cutter in port at the time.
- The utilization of the rapid response team concept should cause fire safety to increase because firefighting will commence sooner in the fire growth period.
- The new fire detection and monitoring system should increase fire safety due to increased probability of detection. Probability of detection is improved with a fully addressable system, since time is not wasted in determining the exact location of the fire. In addition, automatic notification of the Bridge is improved, since the system reports the location of the fire instead of relying on an accurate relay of information from an investigator.
- Manning one repair party instead of two repair parties should decrease fire safety due to a loss in manual firefighting effectiveness.

The net effect of these changes is shown in Tables 4.5, 4.6, and 4.7. In these tables the pre- and post-Paragon results are shown for comparable scenarios and the net improvement in fire safety is calculated. For the 14 compartments shown in Tables 4.5, 4.6, and 4.7, there is an average net improvement in the margin of safety (increased fire safety) of 30.5% in the YOKE at-sea scenario, an 15.3% increase in the margin of safety in the in-port in-homeport XRAY scenario, and a 28.9% increase in the margin of safety in the in-port away-from-homeport XRAY scenario. The 14 compartments listed in these tables have a MAL of 1, 2, or 3 and a RLF greater than 0.03 in Scenario 1. Therefore it should not be concluded that these increases in the margin of safety apply to all compartments in the cutter.

Table 4.5
Relative Loss Factors, Scenario 3

Plan ID	Compartment Name	CUI	MAL	FAL	Run 6-17 Scenario 3 I, A, & M Baseline	Run 14-63 Scenario 3 I, A, & M Post Paragon	Percent Improvement
4-108-0-E	Engine Room	EM	2	26	0.019	0.011	40.2%
01-99-0-Q	Uptake & Fan Room	TU	2	23	0.102	0.081	20.6%
03-62-0-C	Pilot House	C	2	26	0.099	0.073	26.0%
02-56-1-C	Radio Room	C	2	26	0.060	0.046	24.0%
02-90-0-Q	Plenum Room	QF	3	18	0.042	0.035	17.7%
02-56-2-C	CIC Room	C	2	26	0.041	0.031	23.8%
1-108-0-Q	Uptake	TU	2	23	0.040	0.032	20.3%
01-92-0-Q	Helo Service Room	QA	2	22	0.039	0.030	23.0%
1-114-2-Q	Scullery	QG	2	20	0.038	0.026	33.2%
2-172-1-A	Hawser & Rescue Equipment	AS	2	22	0.022	0.013	42.3%
1-20-0-Q	Laundry	QL	3	19	0.000	0.000	N/A
1-93-0-L	CPO Mess	LL	2	24	0.033	0.021	36.3%
1-121-0-L	Crews Mess	LL	2	24	0.032	0.018	43.3%
4-188-0-E	Steering Gear Room	QA	2	26	0.008	0.005	45.1%
						Average	30.5%

Compartments listed have
MAL of 1-3 and RLF>.03 in Scenario 1

All Scenarios are YOKE At Sea

Table 4.6
Relative Loss Factors, Scenario 1

Comparison Post-Paragon and Baseline Results
In Port In Homeport

Plan ID	Compartment Name	CUI	MAL	FAL	Run 10-37	Run 15-67	
					Scenario 1	Scenario 1	Percent
					I, A, & M	I, A, & M	Improvement
					Baseline	Post Paragon	
4-108-0-E	Engine Room	EM	2	26	0.338	0.306	9.3%
01-99-0-Q	Uptake & Fan Room	TU	2	23	0.105	0.094	11.3%
03-62-0-C	Pilot House	C	2	26	0.104	0.107	-3.1%
02-56-1-C	Radio Room	C	2	26	0.062	0.059	4.9%
02-90-0-Q	Plenum Room	QF	3	18	0.044	0.039	12.0%
02-56-2-C	CIC Room	C	2	26	0.042	0.039	7.4%
1-108-0-Q	Uptake	TU	2	23	0.041	0.034	17.0%
01-92-0-Q	Helo Service Room	QA	2	22	0.040	0.035	11.6%
1-114-2-Q	Scullery	QG	2	20	0.038	0.027	28.9%
2-172-1-A	Hawser & Rescue Equipment	AS	2	22	0.038	0.027	28.0%
1-20-0-Q	Laundry	QL	3	19	0.036	0.031	15.4%
1-93-0-L	CPO Mess	LL	2	24	0.034	0.027	20.9%
1-121-0-L	Crews Mess	LL	2	24	0.033	0.024	27.0%
4-188-0-E	Steering Gear Room	QA	2	26	0.032	0.025	23.2%
						Average	15.3%

Compartments listed have
MAL of 1-3 and RLF>.03 in Scenario 1

All Scenarios are XRAY In Port

Table 4.7
Relative Loss Factors, Scenario 1

Comparison Post-Paragon and Baseline Results
In Port Away From Homeport

Plan ID	Compartment Name	CUI	MAL	FAL	Run 10-37 Scenario 1 I, A, & M Baseline	Run 16-75 Scenario 1 I, A, & M Post Paragon	Percent Improvement
4-108-0-E	Engine Room	EM	2	26	0.338	0.272	19.4%
01-99-0-Q	Uptake & Fan Room	TU	2	23	0.105	0.083	21.5%
03-62-0-C	Pilot House	C	2	26	0.104	0.077	25.3%
02-56-1-C	Radio Room	C	2	26	0.062	0.047	24.2%
02-90-0-Q	Plenum Room	QF	3	18	0.044	0.036	18.4%
02-56-2-C	CIC Room	C	2	26	0.042	0.031	26.9%
1-108-0-Q	Uptake	TU	2	23	0.041	0.033	20.1%
01-92-0-Q	Helo Service Room	QA	2	22	0.040	0.031	23.0%
1-114-2-Q	Scullery	QG	2	20	0.038	0.026	33.3%
2-172-1-A	Hawser & Rescue Equipment	AS	2	22	0.038	0.019	49.6%
1-20-0-Q	Laundry	QL	3	19	0.036	0.025	30.8%
1-93-0-L	CPO Mess	LL	2	24	0.034	0.022	36.8%
1-121-0-L	Crews Mess	LL	2	24	0.033	0.018	43.6%
4-188-0-E	Steering Gear Room	QA	2	26	0.032	0.022	32.3%
						Average	28.9%

Compartments listed have
MAL of 1-3 and RLF>.03 in Scenario 1

All Scenarios are XRAY In Port

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5. CONCLUSIONS AND RECOMMENDATIONS

The primary objectives of this project are to analyze the fire safety of the CGC DEPENDABLE before and after the changes associated with the Paragon project were implemented on the cutter and to quantify the net effect of these changes. The analysis was performed using the SFSEM/SAFE with the individual target option specified for the output data. The input data was collected during ship visits and is documented in the Appendices of this report.

The conclusions and recommendations from this study are discussed in the following sections of this report.

5.1 CONCLUSIONS

The following conclusions are supported by the baseline fire safety analysis, the analysis of the post-Paragon conditions, and a comparison of the results from these analyses discussed in Sections 3 and 4 of this report:

- Some of the changes implemented on DEPENDABLE as a result of the Paragon Project increase the fire safety of the cutter, while other changes have an adverse effect on fire safety. The net effect on the fire safety of the DEPENDABLE as a result of changes implemented in conjunction with the Paragon project is significantly positive or beneficial for all scenarios. For the 14 compartments shown in Tables 4.5, 4.6, and 4.7, the average increase in fire safety varies from 15.3% for the in homeport, XRAY, scenario to 30.5% for the at sea, YOKE, scenario.
- The baseline (pre-Paragon) fire safety analysis results show that all compartments in the pre-Paragon DEPENDABLE exceed FSOs, in port and at sea. Moreover, all compartments exceed FSOs with just passive fire protection in effect. Automated fire protection systems and manual firefighting efforts serve to increase the margin of safety provided by passive fire protection. This means that no improvements are necessarily required to bring the pre-Paragon DEPENDABLE up to minimally acceptable fire safety levels.
- The post-Paragon fire safety analysis results show that all compartments in the post-Paragon DEPENDABLE exceed FSOs, in port and at sea. Furthermore, all compartments exceed FSOs with just passive fire protection in effect. Automated fire protection systems and manual firefighting efforts serve to increase the margin of safety provided by passive fire protection. This means that no improvements are necessarily required to bring the post-Paragon DEPENDABLE up to minimally acceptable fire safety levels.
- The original fire detection system was not addressable and was generally considered to be unreliable. The new fire detection system is fully addressable and is integrated with other alarms such as the magazine high temperature alarm and the high bilge level alarm. It is also designed to interface with the general announcing system and the 16 surveillance cameras installed throughout the ship. The wireless internal communications devices have benefits besides their obvious use in damage control and firefighting operations. Some of these changes have not been fully implemented. The effect of fully implementing these changes should further increase the fire safety of the cutter.

5.2 RECOMMENDATIONS

The following recommendations are based on the results of the baseline fire safety analysis, the analysis of the post-Paragon conditions, and a comparison of the results from these analyses discussed in Sections 3 and 4 of this report:

- The fire safety of the post-Paragon DEPENDABLE is greater than the pre-Paragon DEPENDABLE. The increase in fire safety is primarily attributable to the new fire detection and monitoring system and implementation of the rapid response team concept. It is recommended that these changes be implemented on all other cutters in the 210'WMEC class, regardless if other Paragon changes are implemented.
- The benefits of a fully addressable fire detection system and the rapid response team concept would benefit all cutters in the Coast Guard. The Coast Guard should consider revising the firefighting procedures in all cutters to incorporate a rapid response team concept. The new fire detection and monitoring system was installed using the original wiring and replacing the existing detectors with new, addressable detectors. It is recommended that all cutters with a fire detection system that can be similarly modified should be changed to a fully addressable system.
- The new fire detection and monitoring system has not been fully implemented in DEPENDABLE due to technical difficulties encountered during installation. It is recommended that this system be fully implemented to take full advantage of the increase in fire safety offered by the new system.
- The portable personal communication devices discussed in this report have benefits beyond damage control and firefighting that result in efficient day to day operations. These devices should be considered for use on all cutters in the Coast Guard.

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